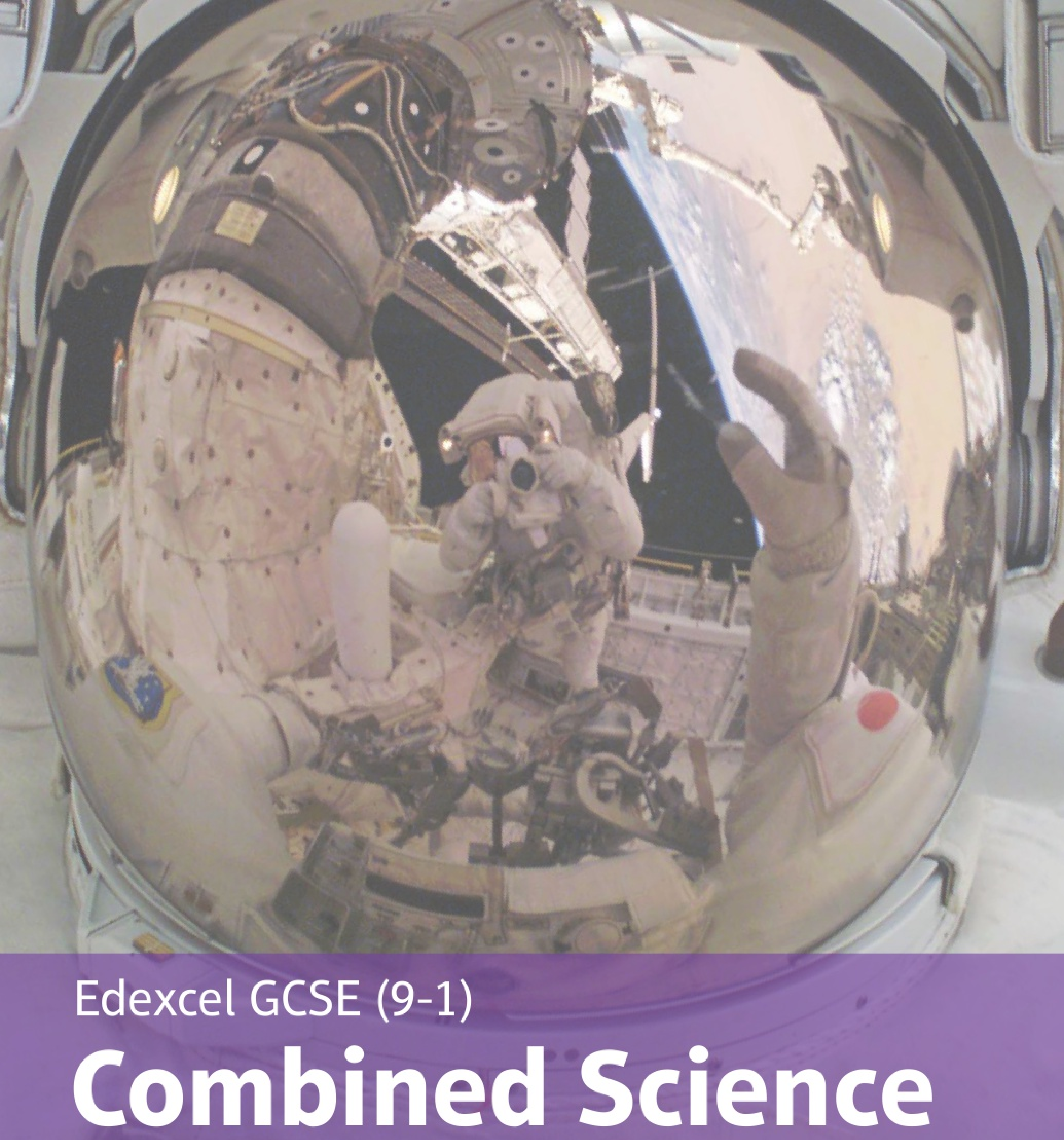


Edexcel GCSE (9-1)

Combined Science

Mark Levesley Penny Johnson Sue Kearsey Iain Brand Nigel Saunders John Ling
Sue Robilliard Carol Tear

ALWAYS LEARNING

PEARSON

Contents

Teaching and learning vi

CB1 **Key Concepts in Biology** (Paper 1 and Paper 2) 1
CB1a Microscopes 2
CB1b Plant and animal cells 4
CB1b Core practical – Using microscopes 6
CB1c Specialised cells 8
CB1d Inside bacteria 10
CB1e Enzymes and nutrition 12
CB1f Enzyme action 14
CB1g Enzyme activity 16
CB1g Core practical – pH and enzymes 18
CB1h Transporting substances 20
CB1h Core practical – Osmosis in potato slices 22
CB1 Preparing for your exams 24

CB2 **Cells and Control** (Paper 1) 25
CB2a Mitosis 26
CB2b Growth in animals 28
CB2c Growth in plants 30
CB2d Stem cells 32
CB2e The nervous system 34
CB2f Neurotransmission speeds 36
CB2 Preparing for your exams 38

CB3 **Genetics** (Paper 1) 39
CB3a Meiosis 40
CB3bi DNA 42
CB3bii DNA extraction 44
CB3c Alleles 46
CB3d Inheritance 48
CB3e Gene mutation 50
CB3f Variation 52
CB3 Preparing for your exams 54

CC1 **States of Matter**
CC2 **Methods of Separating and Purifying Substances** (Paper 3) 55
CC1a States of matter 56
CC2a Mixtures 58
CC2b Filtration and crystallisation 60
CC2c Paper chromatography 62
CC2d Distillation 64
CC2d Core practical – Investigating inks 66
CC2e Drinking water 68
CC1/2 Preparing for your exams 70

CC3 **Atomic Structure** (Paper 3 and Paper 4) 71
CC3a Structure of an atom 72
CC3b Atomic number and mass number 74
CC3c Isotopes 76
CC3 Preparing for your exams 78

CC4 The Periodic Table (Paper 3 and Paper 4) 79
CC4a Elements and the periodic table 80
CC4b Atomic number and the periodic table 82
CC4c Electronic configurations and the periodic table 84
CC4 Preparing for your exams 86

CC5 Ionic Bonding
CC6 Covalent Bonding
CC7 Types of Substance (Paper 3 and Paper 4) 87
CC5a Ionic bonds 88
CC5b Ionic lattices 90
CC5c Properties of ionic compounds 92
CC6a Covalent bonds 94
CC7a Molecular compounds 96
CC7b Allotropes of carbon 98
CC7c Properties of metals 100
CC7d Bonding models 102
CC5/6/7 Preparing for your exams 104

CP1 Motion (Paper 5) 105
CP1a Vectors and scalars 106
CP1b Distance/time graphs 108
CP1c Acceleration 110
CP1d Velocity/time graphs 112
CP1 Preparing for your exams 114

CP2 Forces and Motion (Paper 5) 115
CP2a Resultant forces 116
CP2b Newton's First Law 118
CP2c Mass and weight 120
CP2d Newton's Second Law 122
CP2d Core practical – Investigating acceleration 124
CP2e Newton's Third Law 126
CP2f Momentum 128
CP2g Stopping distances 130
CP2h Crash hazards 132
CP2 Preparing for your exams 134

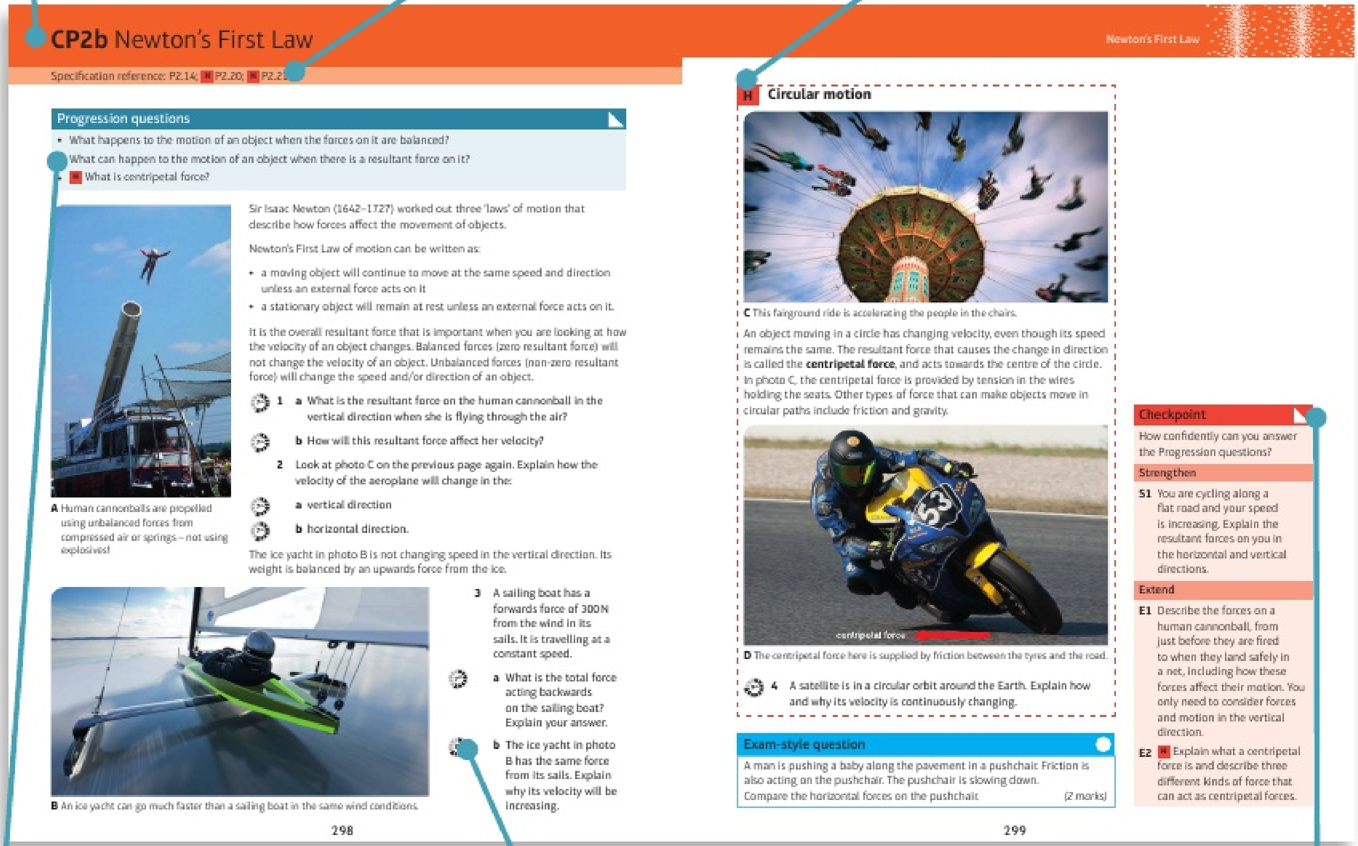
CP3 Conservation of Energy (Paper 5) 135
CP3a Energy stores and transfers 136
CP3b Energy efficiency 138
CP3c Keeping warm 140
CP3d Stored energies 142
CP3e Non-renewable resources 144
CP3f Renewable resources 146
CP3 Preparing for your exams 148

Teaching and learning

The **topic reference** tells you which part of the course you are in. 'CP2b' means, 'Combined Science, Physics, unit 2, topic b'.

The **specification reference** allows you to cross reference against the specification criteria so you know which parts you are covering.

If you see an **H** icon that means that content will be assessed on the Higher Tier paper only.



CP2b Newton's First Law

Specification reference: P2.14; H P2.20; H P2.2

Progression questions

- What happens to the motion of an object when the forces on it are balanced?
- What can happen to the motion of an object when there is a resultant force on it?
- H What is centripetal force?

A Human cannonballs are propelled using unbalanced forces from compressed air or springs – not using explosives!

Sir Isaac Newton (1642–1727) worked out three 'laws' of motion that describe how forces affect the movement of objects.

Newton's First Law of motion can be written as:

- a moving object will continue to move at the same speed and direction unless an external force acts on it
- a stationary object will remain at rest unless an external force acts on it.

It is the overall resultant force that is important when you are looking at how the velocity of an object changes. Balanced forces (zero resultant force) will not change the velocity of an object. Unbalanced forces (non-zero resultant force) will change the speed and/or direction of an object.

1 a What is the resultant force on the human cannonball in the vertical direction when she is flying through the air?

b How will this resultant force affect her velocity?

2 Look at photo C on the previous page again. Explain how the velocity of the aeroplane will change in the:

a vertical direction

b horizontal direction.

The ice yacht in photo B is not changing speed in the vertical direction. Its weight is balanced by an upwards force from the ice.

B An ice yacht can go much faster than a sailing boat in the same wind conditions.

3 A sailing boat has a forwards force of 300 N from the wind in its sails. It is travelling at a constant speed.

a What is the total force acting backwards on the sailing boat? Explain your answer.

b The ice yacht in photo B has the same force from its sails. Explain why its velocity will be increasing.

298

Newton's First Law

H Circular motion

C This fairground ride is accelerating the people in the chairs.

An object moving in a circle has changing velocity, even though its speed remains the same. The resultant force that causes the change in direction is called the **centripetal force**, and acts towards the centre of the circle. In photo C, the centripetal force is provided by tension in the wires holding the seats. Other types of force that can make objects move in circular paths include friction and gravity.

centripetal force

D The centripetal force here is supplied by friction between the tyres and the road.

4 A satellite is in a circular orbit around the Earth. Explain how and why its velocity is continuously changing.

Exam-style question

A man is pushing a baby along the pavement in a pushchair. Friction is also acting on the pushchair. The pushchair is slowing down.
Compare the horizontal forces on the pushchair. *(2 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 You are cycling along a flat road and your speed is increasing. Explain the resultant forces on you in the horizontal and vertical directions.

Extend

E1 Describe the forces on a human cannonball, from just before they are fired to when they land safely in a net, including how these forces affect their motion. You only need to consider forces and motion in the vertical direction.

E2 H Explain what a centripetal force is and describe three different kinds of force that can act as centripetal forces.

299

By the end of the topic you should be able to confidently answer the **Progression questions**. Try to answer them before you start and make a note of your answers. Think about what you know already and what more you need to learn.

Each question has been given a **Pearson Step** from 1 to 12. This tells you how difficult the question is. The higher the step the more challenging the question.

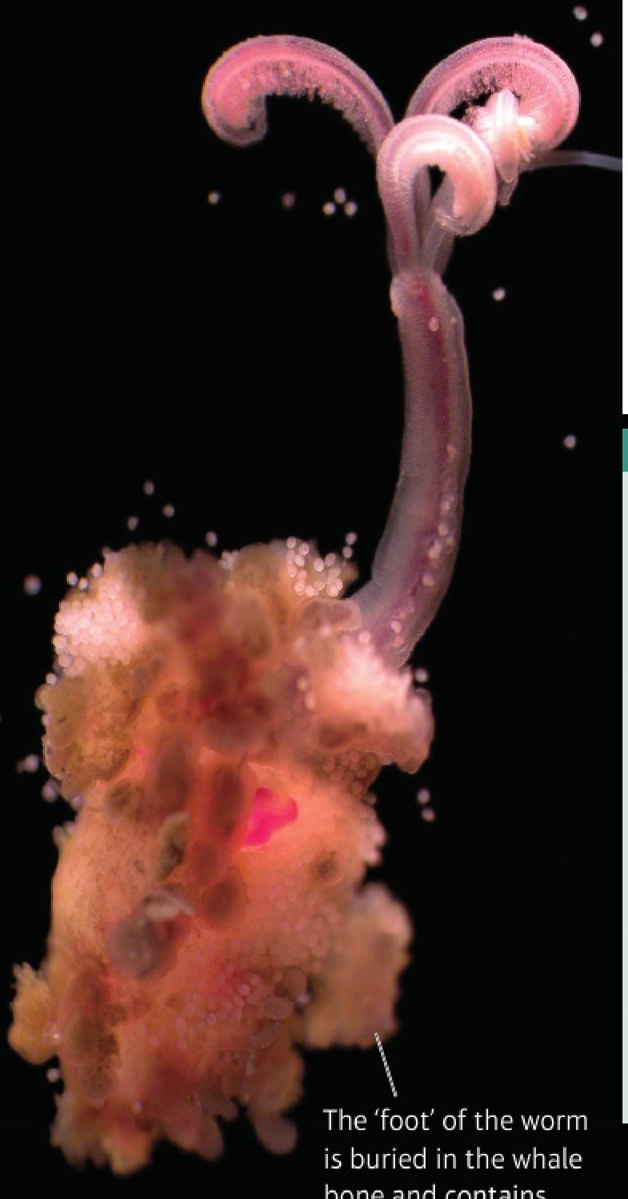
When you've worked through the main student book questions, answer the **Progression questions** again and review your own progress. Decide if you need to reinforce your own learning by answering the **Strengthen question**, or apply, analyse and evaluate your learning in new contexts by tackling the **Extend question**.

Paper 1 and Paper 2

CB1 Key Concepts in Biology

The bone-eating snot-flower worm (*Osedax mucofloris)* has no digestive system but still manages to feed on one of the hardest substances produced by vertebrate animals – their bones. These worms are a type of zombie worm, so-called because they have no eyes or mouth, and were discovered in the North Sea in 2005 feeding on a whale skeleton. Enzymes in the 'foot' of the worm cause the production of an acid, which attacks bone and releases lipids and proteins from inside the bone. Enzymes in bacteria on the foot of the worm then digest these large organic molecules into smaller molecules that the worms absorb (using processes such as diffusion).

In this unit you will learn about some of the central ideas in biology, including ideas about cells, microscopy, enzymes, nutrition, diffusion, osmosis and active transport.


The 'foot' of the worm is buried in the whale bone and contains many bacteria.

The learning journey

Previously you will have learnt at KS3:

- how to use a microscope
- about the differences between cells from different organisms
- how some cells are specialised and adapted to their functions
- how enzymes help to digest food in the digestive system
- how substances can move by diffusion.

In this unit you will learn:

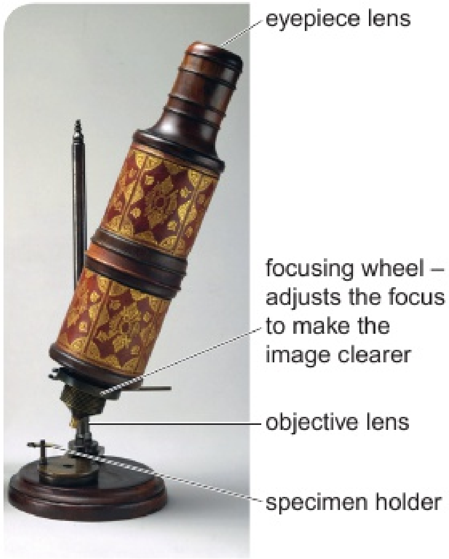
- how developments in microscopy have allowed us to find out more about the sub-cellular structures found in plant, animal and bacterial cells
- about the importance of enzymes in nutrition, growth and development
- how enzymes are affected by pH and temperature and why each enzyme only works on a certain type of molecule
- how substances are carried by diffusion, osmosis and active transport.

CB1a Microscopes

Specification reference: B1.3; B1.4; B1.5

Progression questions

- What determines how good a microscope is at showing small details?
- What has the development of the electron microscope allowed us to do?
- What units are used for very small sizes?


eyepiece lens
focusing wheel – adjusts the focus to make the image clearer
objective lens
specimen holder

A Hooke's microscope

The most common microscope used today contains two lenses and was invented at the end of the 16th century. Robert Hooke (1635–1703) used a microscope like this to discover cells in 1665.

Hooke's microscope had a **magnification** of about ×30 (it made things appear about 30 times bigger). A person magnified 30 times would be roughly the size of the Statue of Liberty in New York.

1 **a** A photo of a water flea says it is magnified ×50. What does this mean?

b On the photo, the flea is 5 cm long. Calculate the unmagnified length of the water flea.

To work out a microscope's magnification, you *multiply* the magnifications of its two lenses together. So, the magnification of a microscope with a ×5 **eyepiece lens** and ×10 **objective lens** is:

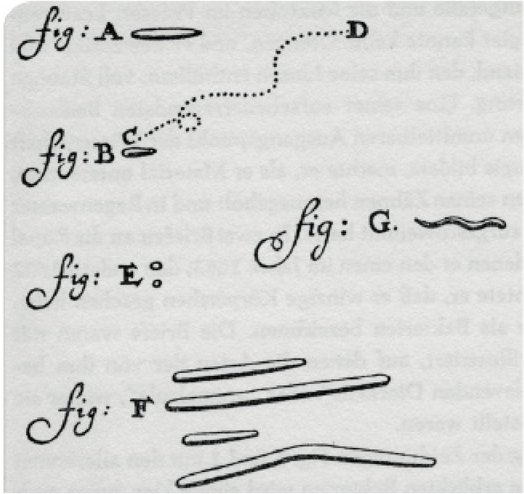
$$5 \times 10 = \times 50$$

2 A microscope has a ×5 eyepiece lens with ×5, ×15 and ×20 objective lenses. Calculate its three total magnifications.

B replica of a van Leeuwenhoek microscope

Hooke's microscope was not very powerful because the glass lenses were of poor quality. Antonie van Leeuwenhoek (1632–1723) found a way of making much better lenses, although they were very small. He used these to construct microscopes with single lenses, which had magnifications of up to ×270. In 1675, he examined a drop of rainwater and was surprised to find tiny organisms, which he called 'animalcules'. Fascinated by his discovery, he searched for 'animalcules' in different places.

3 The top bacterium in photo C is 0.002 mm long in real life. At what magnification is the drawing?



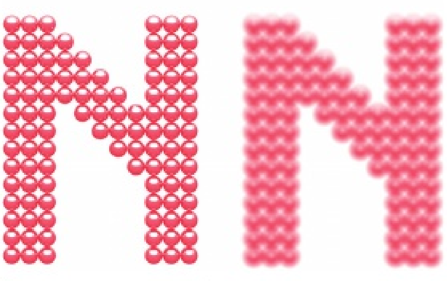
C These are van Leeuwenhoek's drawings of 'animalcules' found in scrapings from his teeth. We call them bacteria.

Did you know?

Van Leeuwenhoek examined his semen and discovered sperm cells.

The detail obtained by a microscope also depends on its **resolution**. This is the smallest distance between two points that can still be seen as two points. Van Leeuwenhoek's best microscopes had a resolution of 0.0014 mm. Two points that were 0.0014 mm or further apart could be seen as two points, but two points closer together than this appeared as a single point.

5th **4** Hooke's microscope had a resolution of about 0.002 mm. What does this mean?



D These images of tiny beads have the same magnification but different resolutions.

With the development of **stains** for specimens, and better lenses and light sources, today's best light microscopes magnify up to ×1500 with resolutions down to about 0.0001 mm.

The electron microscope was invented in the 1930s. Instead of light, beams of electrons pass through a specimen to build up an image. These microscopes can magnify up to ×2 000 000, with resolutions down to 0.0000002 mm. They allow us to see cells with great detail and clarity.

6th **5** Explain why electron microscope images show more detail than light microscopes.

SI units

The measurements on these pages are in millimetres. Adding the 'milli' prefix to a unit divides it by 1000. One metre (m) contains 1000 millimetres (mm). There are other prefixes that often make numbers easier to understand.

Table E

	Prefix	Effect on unit	Example	
	milli-	÷ 1000	millimetres (mm)	
× 1000	micro-	÷ 1 000 000	micrometres (μm)	÷ 1000
× 1000	nano-	÷ 1 000 000 000	nanometres (nm)	÷ 1000
× 1000	pico-	÷ 1 000 000 000 000	picometres (pm)	÷ 1000

7th **6** Give the highest resolution of electron microscopes in micro-, nano- and picometres.

Exam-style question

State two advantages of using an electron microscope to view cells, rather than a light microscope. *(2 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Compare today's light microscopes with Hooke's.

Extend

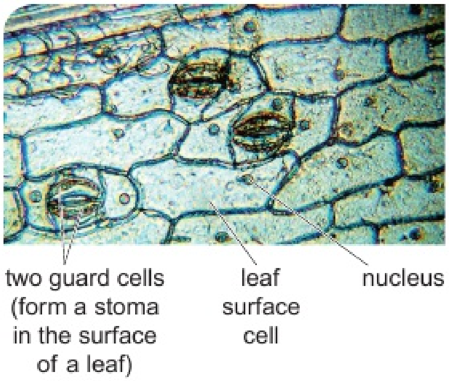
E1 Diatoms are algae, 20–120 μm in length and with 1 μm diameter 'pores' in their outer coats. Van Leeuwenhoek described diatom shapes but not their pores. Explain why.

CB1b Plant and animal cells

Specification reference: B1.1; B1.4; B1.6

Progression questions

- How are animal cells different to plant cells?
- What do the sub-cellular structures in eukaryotic cells do?
- How can we estimate the sizes of cells and their parts?



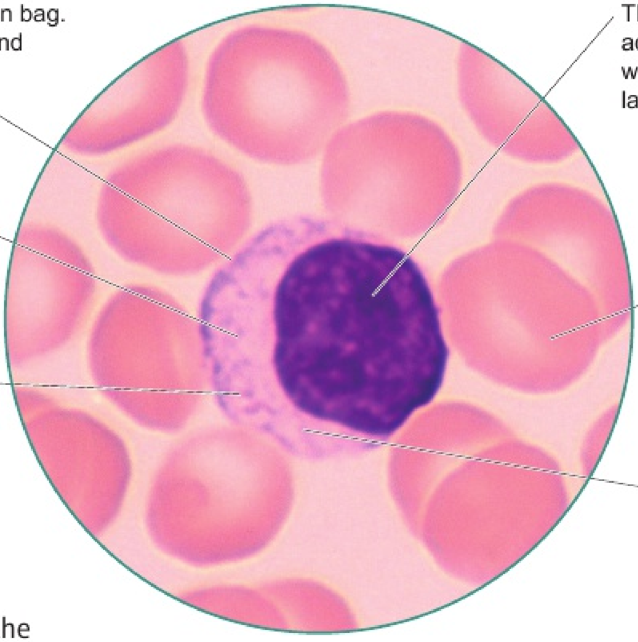
A This micrograph ('microscope picture') was taken using Brown's original microscope, of the same cells in which he discovered nuclei (magnification ×67).

As microscopes improved, scientists saw more details inside cells. In 1828, Robert Brown (1773–1858) examined cells from the surface of a leaf and noticed that each cell contained a small, round blob. He called this the **nucleus** (meaning 'inner part' in Latin).

5th **1** Photo A is at a magnification of 67. State what this means.

Brown wrote a **scientific paper** about his discovery. Matthias Schleiden (1804–1881) read the paper and thought that the nucleus must be the most important part of a plant cell. He mentioned this idea to Theodor Schwann (1810–1882), who then wondered if he could find cells with nuclei in animals. He did. And so the idea of cells being the basic building blocks of all life was born.

A cell with a nucleus is described as **eukaryotic**. We have now discovered many other sub-cellular ('smaller than a cell') structures in eukaryotic cells and worked out what they do.



The **cell membrane** is like a very thin bag. It controls what enters and leaves, and separates one cell from another.

The **cytoplasm** contains a watery jelly and is where most of the cell's activities occur.

One of these blobs is a **mitochondrion** (see photo C). Mitochondria are jelly-bean shaped structures in which **aerobic respiration** occurs. Mitochondria are very difficult to see with a light microscope.

The **nucleus** controls the cell and its activities. Inside it are **chromosomes**, which contain **DNA**. It is especially large in white blood cells.

The cytoplasm also contains tiny round structures called **ribosomes**. These make new proteins for a cell. It is impossible to see them with a light microscope.

B The labelled central cell is a human white blood cell, which has been stained to make its features show up clearly (magnification ×2500).

5th **2** Draw a table to show the parts of an animal cell and the function of each part.

6th **3** Estimate the diameter of the labelled red blood cell in photo B. Show your working.

The circular area you see in a light microscope is the **field of view**. If we know its diameter, we can estimate sizes. The diameter of the field of view in photo B is 36 μm. We can imagine that three white blood cells will roughly fit across the field of view. So the cell's diameter is about $\frac{36}{3}$ = 12 μm.

Electron micrographs

Photo C shows many parts inside a white blood cell that you cannot see with a light microscope. However, you still cannot see ribosomes because they are only about 25 nm in diameter.

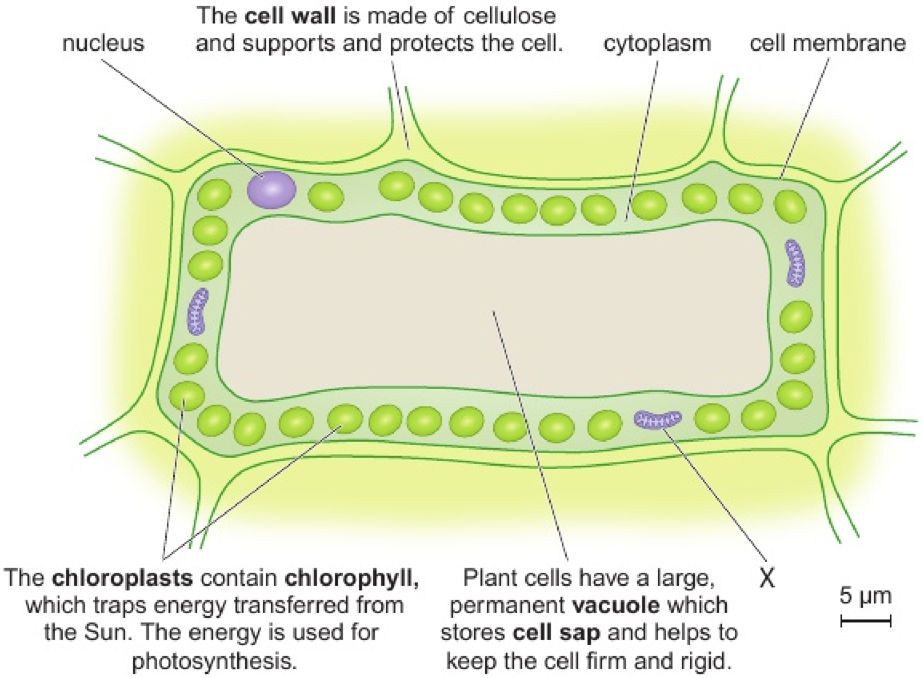
4 **a** Look at photo C. What part has been coloured purple?

b Use the magnification to estimate the width of the cell.

5 State the diameter of a ribosome in micrometres.

Scale bars are often shown on micrographs and these are also used to estimate sizes. The scale bar on photo C shows how long 4 µm is at this magnification. About three of these bars could fit across the cell at its widest point; the cell is about 3 × 4 = 12 µm wide.

Plant cells may have some additional structures compared with animal cells, as shown in diagram D.


nucleus
The **cell wall** is made of cellulose and supports and protects the cell.
cytoplasm
cell membrane
The **chloroplasts** contain **chlorophyll,** which traps energy transferred from the Sun. The energy is used for photosynthesis.
Plant cells have a large, permanent **vacuole** which stores **cell sap** and helps to keep the cell firm and rigid.
X
5 µm

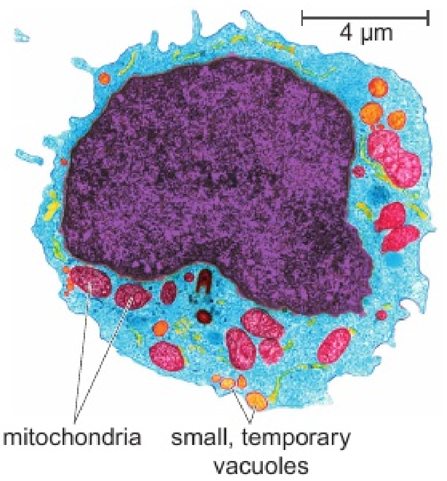
D a cell from inside a plant leaf

7 Look at diagram D. What is part X?

8 Cells on leaf *surfaces* contain vacuoles and carry out aerobic respiration but are not green. Suggest what part they lack. Explain your reasoning.

Exam-style question

Describe the function of chloroplasts in a leaf palisade cell. *(3 marks)*



C electron micrograph of a white blood cell (magnification ×4200)

Did you know?

The pigment in human skin is made in sub-cellular structures called melanosomes.

6 Use the scale bar on photo C to estimate the:

a width of the nucleus at its widest point

b length of the longest mitochondrion (coloured red).

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a plant cell and label its parts, describing what each part does.

Extend

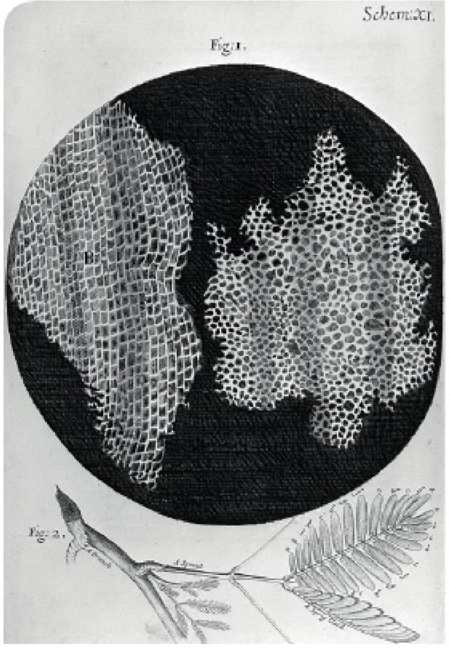
E1 An 'organelle' is a structure inside a cell with a specific function. Compare the organelles found in plant and animal cells.

CB1b Core practical – Using microscopes

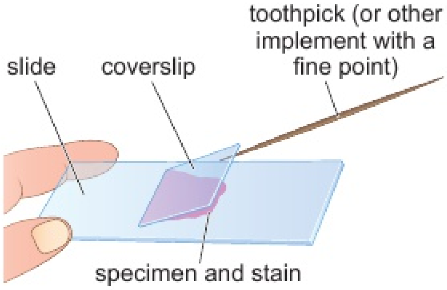
Specification reference: B1.6

Aim

Investigate biological specimens using microscopes, including magnification calculations and labelled scientific drawings from observations.


Schem:XI.
Fig:1.
Fig:2.

A Hooke's drawing of cork cells, published in 1665 in his book *Micrographia*



B Lowering a coverslip slowly and carefully means a slide is less likely to contain air bubbles.

One of the first people to examine cells using a microscope was Robert Hooke. He examined bark from a cork oak tree and saw little box shapes. He called them 'cells' because he thought the boxes looked like the small rooms (or cells) found in monasteries at the time. Hooke also realised the importance of making accurate drawings of what he saw to help explain his work to others.

Your task

You are going to make a slide of some plant or animal tissue and examine it using a microscope. You will then make an accurate drawing of one or more of the cells that you see, and add information to help people understand your drawing (e.g. labelling the cell, adding a scale bar).

Method

Wear eye protection.

A Make sure you understand how the microscopes in the lab work, and how to calculate magnifications (using the numbers on the objective and eyepiece lenses).

B Decide which cells to observe and how you will collect them. Consider using your own cheek cells or pieces of tissue from onion bulbs, rhubarb stems or leaves.

C Collect a small specimen of the cells.

D Add a drop of water or stain to the centre of a microscope slide. Record the name of any stain that you use.

E Place your specimen on the drop of water or stain.

F Use a toothpick to slowly lower a coverslip onto the specimen, as shown in diagram B. The coverslip keeps the specimen flat, holds it in place and stops it drying out.

G Examine your specimen under a microscope. Start with the lowest magnification and work up to higher magnifications.

H Draw one or more of the cells that you see and annotate your drawing appropriately.

Exam-style questions

1 State the name of the part of a microscope where you would place the slide. *(1 mark)*

2 Photo C shows a light microscope.

- **a** Give the letter of the part that is an objective lens. *(1 mark)*
- **b** Give the letter of a part that is used to focus an image. *(1 mark)*

3 State why the lowest power magnification is used when first examining a specimen. *(1 mark)*

4 A microscope is fitted with three objective lenses (of ×2, ×5 and ×10).

- **a** State what ×2 on a lens means. *(1 mark)*
- **b** The microscope has a ×7 eyepiece lens. Calculate the possible total magnifications. Show your working. *(3 marks)*

5 Luka has made a slide of some onion tissue. When he examines the specimen with a light microscope, he sees large, thick-walled circles that make it difficult to observe the cells.

- **a** Give the reason for Luka's observation. *(1 mark)*
- **b** State how he could prepare a better slide. *(1 mark)*

6 When looking at plant root tissue under a microscope, Jenna notices that about 10 cells fit across the field of view. She calculates the diameter of the field of view as 0.2 mm. Estimate the diameter of one cell. Show your working. *(2 marks)*

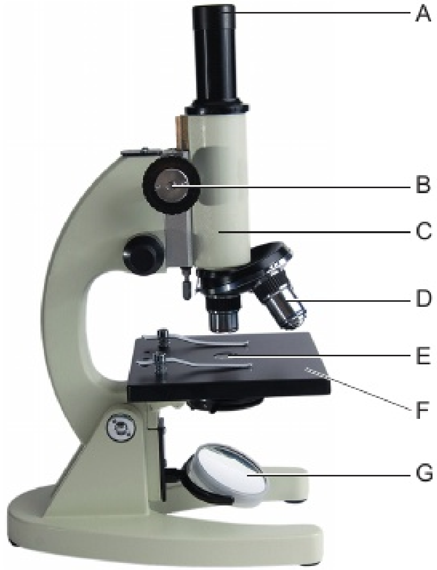
7 Photo D shows a certain type of white blood cell called a neutrophil. The image was taken using an electron microscope.

- **a** State one advantage of using an electron microscope rather than a light microscope. *(1 mark)*
- **b** Calculate the diameter of the cell to the nearest whole micrometre using the scale bar. *(1 mark)*
- **c** Give your answer to part **b** in mm. *(1 mark)*
- **d** Draw the cell and label the nucleus, cell membrane and cytoplasm. *(2 marks)*

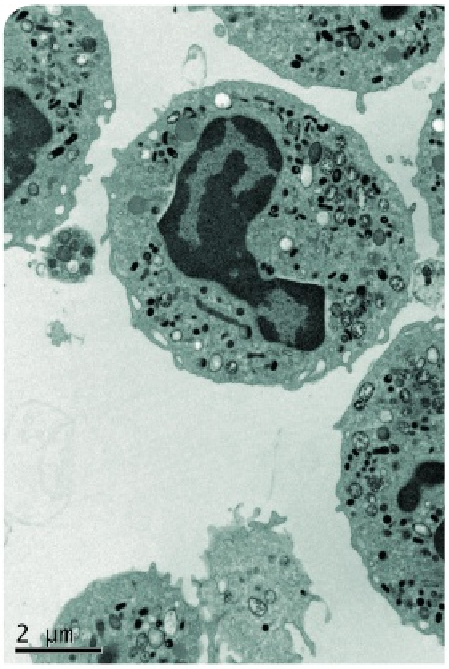
8 Sasha draws a palisade cell from a star anise plant. The cell has a length of 0.45 mm.

- **a** Sasha's drawing is magnified ×500. Calculate the length of the cell in Sasha's drawing. *(1 mark)*
- **b** Sasha adds a scale bar to show 0.1 mm. Calculate the length of the scale bar. *(1 mark)*

9 A heart muscle cell is 20 μm wide. It has been drawn 1 cm wide. Calculate the magnification of the drawing. *(2 marks)*



C a light microscope



D human neutrophils

CB1c Specialised cells

Specification reference: B1.2; B1.4; B1.6

Progression questions

- How are some specialised cells adapted to their functions?
- What is the function of a gamete?
- What is the function of cilia?

Did you know?

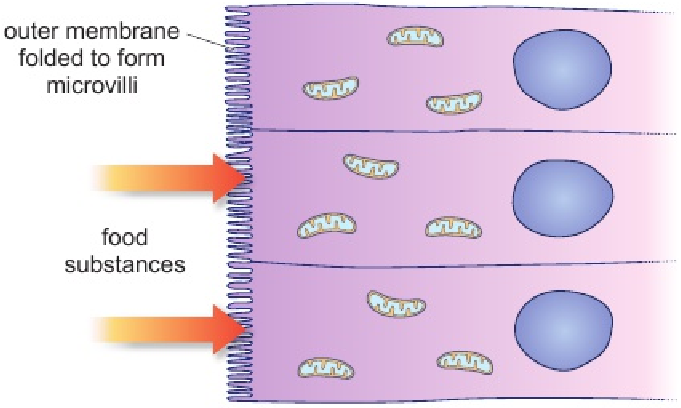
Human nerve cells (neurones) carry information very quickly. Many are adapted by being extremely long, with some reaching lengths of about 1.4 m.

Specialised cells have a specific function (job). There are about 200 different types of specialised cells in humans. All human cells have the same basic design, but their sizes, shapes and sub-cellular structures can be different so that specialised cells are **adapted** to their functions.

5th **1** List three specialised human cells and state their functions.

Specialised cells for digestion

The cells that line the small intestine absorb small food molecules produced by **digestion**. They are adapted by having membranes with many tiny folds (called **microvilli**). These **adaptations** increase the surface area of the cell. The more area for molecules to be absorbed, the faster absorption happens.



A small intestine cells

Cells in an organ called the pancreas make **enzymes** needed to digest certain foods in the small intestine. The enzymes are proteins and so these cells are adapted by having a lot of ribosomes.

The wall of the small intestine has muscles to squeeze food along. The muscle cells require a lot of energy and are adapted by having many mitochondria.

Specialised cells for reproduction

During sexual reproduction, two specialised cells (**gametes**) fuse to create a cell that develops into an **embryo**. Human gametes are the **egg cell** and the **sperm cell**.

Most human cell nuclei contain two copies of the 23 different types of chromosome. Gametes contain just *one* copy of each. This means that the cell produced by **fertilisation** has two copies. Cells with two sets of chromosomes are **diploid** and those with one copy of each chromosome are **haploid**.

5th **2** **a** Draw a small intestine cell and label its parts.

7th **b** These cells are 20 μm long. Add a 10 μm scale bar to your drawing.

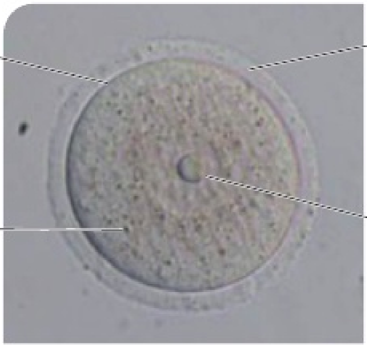
6th **c** Explain why a cell with microvilli absorbs substances more quickly than one without.

7th **3** Cells called hepatocytes make a lot of a substance called serum albumin. These cells contain many ribosomes. Suggest what type of substance serum albumin is. Explain your reasoning.

8th **4** Nerve cells require a lot of energy. Suggest the adaptation that allows them to get enough energy.

6th **5** **a** State whether a sperm cell is haploid or diploid.

7th **b** Explain why it needs to be like this.

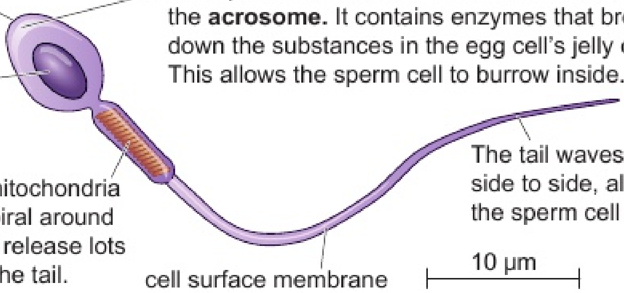


The cell membrane fuses with the sperm cell membrane. After fertilisation, the cell membrane becomes hard to stop other sperm cells entering.

The jelly coat protects the egg cell. It also hardens after fertilisation, to ensure that only one sperm cell enters the egg cell.

The cytoplasm is packed with nutrients, to supply the fertilised egg cell with energy and raw materials for the growth and development of the embryo.

B adaptations of a human female gamete



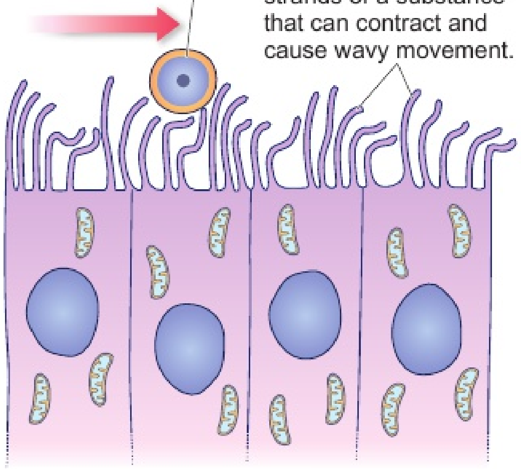
The tip of the head contains a small vacuole called the **acrosome.** It contains enzymes that break down the substances in the egg cell's jelly coat. This allows the sperm cell to burrow inside.

The tail waves from side to side, allowing the sperm cell to swim.

A large number of mitochondria are arranged in a spiral around the top of the tail, to release lots of energy to power the tail.

C adaptations of a human male gamete

Fertilisation occurs in the **oviducts** of the female reproductive system. Cells in the lining of the oviduct transport egg cells (or the developing embryos after fertilisation) towards the uterus. The oviduct cells are adapted for this function by having hair-like **cilia**. These are like short sperm cell tails and wave from side to side to sweep substances along. Cells that line structures in the body are called **epithelial cells**, and epithelial cells with cilia are called **ciliated epithelial cells**.



Cilia are covered in cell membrane and contain strands of a substance that can contract and cause wavy movement.

D adaptations of oviduct lining cells

8th **7** Compare and contrast microvilli and cilia.

6th **8** Explain why an egg cell does not need a tail but a sperm cell does.

Exam-style question

Explain how cells that line the oviduct are adapted to their function of moving the egg cell. *(2 marks)*

5th **6** **a** Make a drawing of a human egg cell and label its parts.

5th **b** Describe how an egg cell is adapted to prevent more than one sperm cell entering.

7th **c** A human egg cell has a diameter of 0.1 mm. Calculate the magnification of your drawing.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 List the steps that occur between an egg cell entering an oviduct and it becoming an embryo, and explain how adaptations of specialised cells help each step.

Extend

E1 Explain how both human gametes are adapted to ensure that the cell produced by fertilisation can grow and develop.

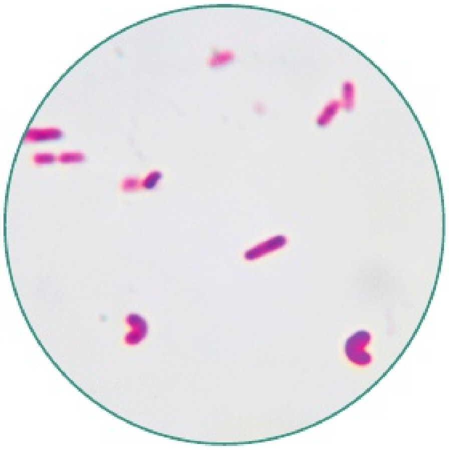
CB1d Inside bacteria

Specification reference: B1.1; **H** B1.5

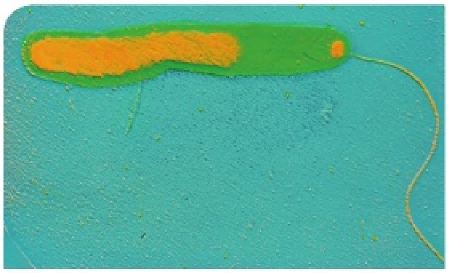
Progression questions

- What are the functions of the sub-cellular structures in bacteria?
- What are the differences between prokaryotic and eukaryotic cells?
- How do we change numbers to and from standard form?

Bacteria are difficult to see with light microscopes because they are very small and mostly colourless. Stains are often used to make them show up.



A light micrograph of *Vibrio cholerae* bacteria stained with safranin (field of view = 20 µm)



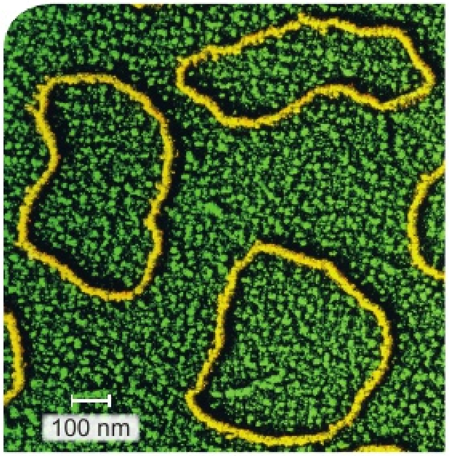
B electron micrograph of *Vibrio cholerae* bacterium, with colours added by a computer (magnification ×22 500)

1 **a** Estimate the size of the longest bacterium in photo A. Explain your reasoning.

b The length of the bacterium in photo B is 4.5 cm (without its tail). Calculate its size in real life. Show all your working.

The extra magnification and resolution of an electron microscope allow scientists to see bacteria in more detail. Photo B shows that this bacterium has a **flagellum**, which spins round like a propeller so the bacterium can move. The yellow colour shows its **DNA**.

Bacteria are **prokaryotic**, which means that their cells do not have nuclei or chromosomes. Instead, the cytoplasm contains one large loop of **chromosomal DNA**, which controls most of the cell's activities. There are also smaller loops of DNA, called **plasmids** (shown in photo C). **Plasmid DNA** controls a few of the cell's activities. Prokaryotic cells do not have mitochondria or chloroplasts.



C electron micrograph of plasmids from a bacterium (magnification ×50 000)

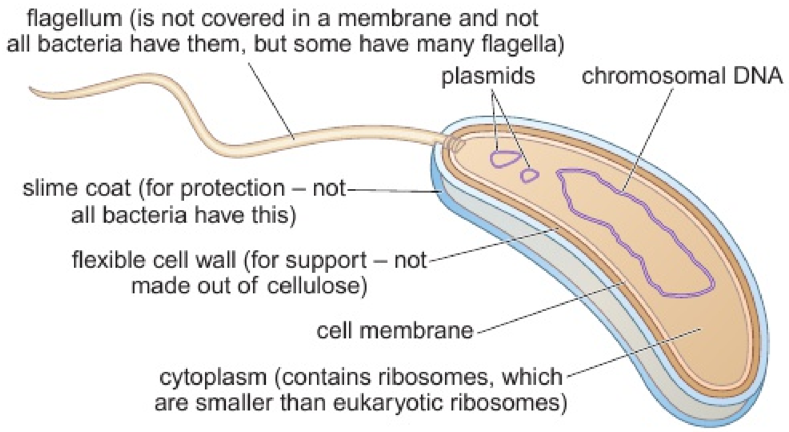
2 **a** Describe the location of the plasmid in photo B.

b Give the name of the substance it is made from.

c Where is this substance mainly found in a eukaryotic cell?

3 Describe the function of a bacterium's flagellum.

Information from microscope images and other work has allowed scientists to discover more about the parts of bacterial cells and their functions, as shown in diagram D.


flagellum (is not covered in a membrane and not all bacteria have them, but some have many flagella)
plasmids
chromosomal DNA
slime coat (for protection – not all bacteria have this)
flexible cell wall (for support – not made out of cellulose)
cell membrane
cytoplasm (contains ribosomes, which are smaller than eukaryotic ribosomes)

D Different bacteria are different shapes and sizes but usually have these parts.

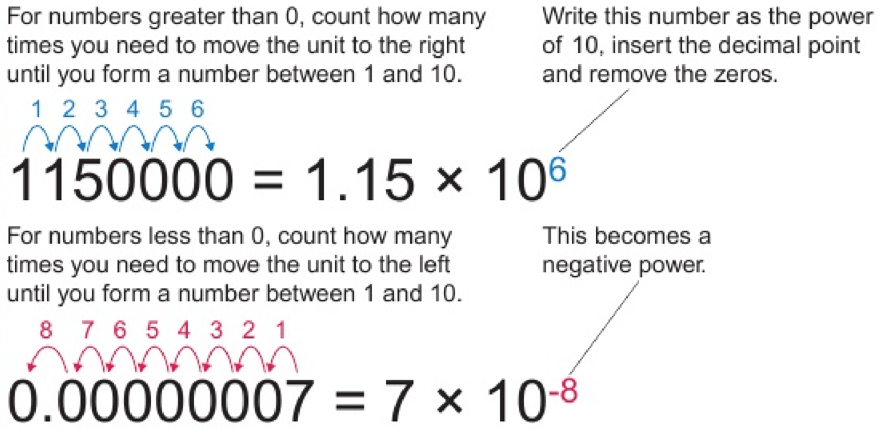
H Standard form

A prokaryotic ribosome is 20 nm in diameter and a football is 0.22 m in diameter. It is hard to compare these sizes because they have different units.

1 m is 1 000 000 000 nm, so a football is 220 000 000 nm in diameter. The units are now the same but figures with so many zeros can be difficult to read and use. To solve this problem, we can show figures in the form of a number between 1 and 10 multiplied by a power of 10.

$$A \times 10^n$$

where A is between 1 and 10 and n is the power of 10; n is also called the **index** number. This is **standard form**. The index number tells you how many place values to move the digit.


For numbers greater than 0, count how many times you need to move the unit to the right until you form a number between 1 and 10.

Write this number as the power of 10, insert the decimal point and remove the zeros.

$$1150000 = 1.15 \times 10^6$$

For numbers less than 0, count how many times you need to move the unit to the left until you form a number between 1 and 10.

This becomes a negative power.

$$0.00000007 = 7 \times 10^{-8}$$

E writing numbers in standard form

Make sure you know how to input numbers in standard form on your calculator.

Exam-style question

State two sub-cellular parts that bacterial cells may have but animal cells never have. *(2 marks)*

4 Draw a table to show the functions of the different parts of a bacterial cell.

5 Estimate the diameter of one plasmid shown in photo C.

6 Suggest why ribosomes are not shown on diagram D.

Did you know?

Your body contains more bacterial cells than human cells. Most of these are found in the digestive system.

7 Make a copy of table E from CB1a, adding another column to show in standard form the effect of adding each prefix. For example, 'milli-' divides a number by a thousand, which in standard form is the same as multiplying by 10^{-3}.

8 Write the diameters of a ribosome and a football in metres in standard form.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a bacterium and label its parts, describing what each part does.

Extend

E1 Compare eukaryotic and prokaryotic cells.

CB1e Enzymes and nutrition

Specification reference: B1.12

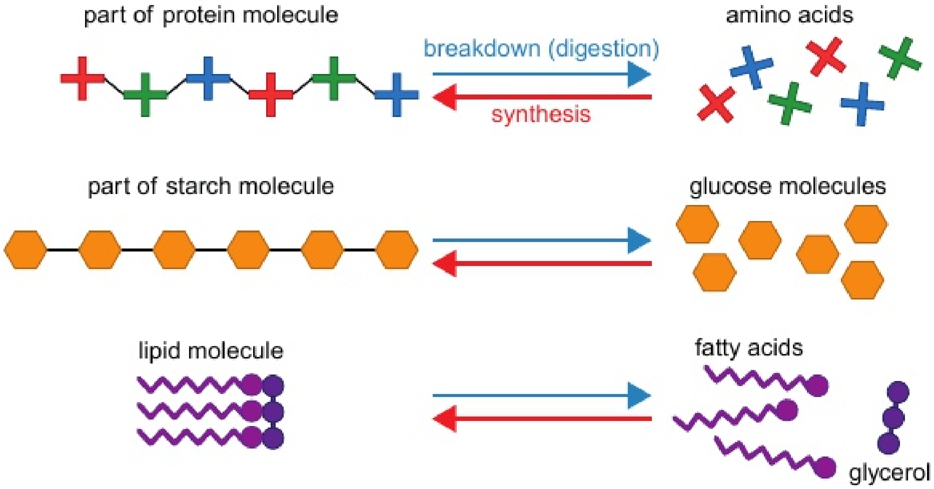
Progression questions

- What are enzymes made out of?
- What do enzymes do?
- Why are enzymes important for life?

A To eat large items of food, a starfish pushes its stomach out of its mouth and into the food. The stomach surface releases enzymes to break down the food, which can then be absorbed.

Most animals get substances for energy, growth and development by digesting food inside their bodies. Bacteria, on the other hand, release digestive enzymes into their environments and then absorb digested food into their cells. Starfish use a similar trick for large items of food.

In humans, digestive enzymes turn the large molecules in our food into the smaller subunits they are made of. The digested molecules are then small enough to be absorbed by the small intenstine.



B Large molecules such as complex carbohydrates, proteins and lipids (fats and oils) are built from smaller molecules.

Once the small molecules are absorbed into the body, they can be used to build the larger molecules that are needed in cells and tissues. Building larger molecules from smaller subunits is known as **synthesis**. Complex carbohydrates and proteins are both **polymers** because they are made up of many similar small molecules, or **monomers**, joined in a chain.

1 Which small molecules make up the following large molecules?

6th **a** carbohydrates

6th **b** proteins

6th **c** lipids

7th **2** When you chew a piece of starchy bread for a while it starts to taste sweet. Suggest a reason for this.

3 Which monomers make up:

6th **a** proteins

6th **b** carbohydrates?

The breakdown of large molecules happens incredibly slowly and only if the bonds between the smaller subunits have enough energy to break. Synthesis also happens very slowly, since the subunits rarely collide with enough force or in the right orientation to form a bond. These reactions happen much too slowly to supply all that the body needs to stay alive and be active.

Many reactions can be speeded up using a **catalyst**. In living organisms, the catalysts that speed up breakdown (e.g. digestion) and synthesis reactions are enzymes. So enzymes are **biological catalysts** that increase the rate of reactions. Enzymes are a special group of proteins that are found throughout the body. The substances that enzymes work on are called **substrates**, and the substances that are produced are called **products**.

6th **4** Define the term 'biological catalyst'.

6th **5** **a** Which type of smaller molecule are enzymes built from?

7th **b** Explain your answer.

Enzyme name	Where found	Reaction catalysed
amylase	saliva and small intestine	breaking down starch to small sugars, such as maltose
catalase	most cells, but especially liver cells	breaking down hydrogen peroxide made in many cell reactions to water and oxygen
starch synthase	plant	synthesis of starch from glucose
DNA polymerase	nucleus	synthesis of DNA from its monomers

C examples of enzymes, where they are found and what they do

6th **6** Name the substrate of amylase, and the products of the reaction it catalyses.

6th **7** Give two examples of processes that are controlled by enzymes in the human body.

7th **8** Suggest what will happen in the cells of someone who does not make phenylalanine hydroxylase. Explain your answer.

8th **9** Sketch a diagram or flowchart to explain how the starfish in photo A absorbs food molecules into its body.

Exam-style question

Explain why the role of enzymes as catalysts in digestion is important for life. *(3 marks)*

Did you know?

The heel prick test takes a small amount of blood to test for several factors, including the enzyme phenylalanine hydroxylase. This enzyme catalyses the breakdown of an amino acid called phenylalanine. A few babies are born without the ability to make the enzyme, which can result in nerve and brain damage as they grow older.

D Babies are given the heel prick test before they are a week old.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a concept map that includes all the important points on these pages. Link words to show how they are related.

Extend

E1 Many bacteria have flexible cell walls made by linking together chains of a polymer. The links are formed in reactions catalysed by an enzyme. Penicillin stops this enzyme from working. Explain how penicillin causes bacteria to be weakened.

CB1f Enzyme action

Specification reference: B1.7; B1.8

Progression questions

- What is the function of the active site of an enzyme?
- Why do enzymes only work on specific substrates?
- How are enzymes denatured?

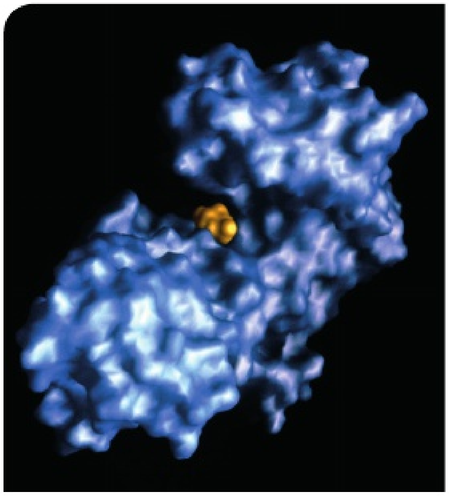
Did you know?

There are about 3000 different enzymes in the human body, catalysing reactions that would otherwise not occur. For example, an enzyme called OMP decarboxylase helps to produce a substance used to make DNA in 18 milliseconds. Without the enzyme, this reaction would take 78 million years!

A The bombardier beetle repels attackers by releasing a very hot, foul liquid. The liquid is made by enzymes that rapidly break down substances (including hydrogen peroxide) in a reaction chamber at the end of the beetle's body.

A protein is a large three-dimensional (3D) molecule formed from a chain of amino acids. The 3D shape is caused by folding of the chain, which depends on the sequence of the amino acids in the chain. The 3D shape of enzymes is important in how they work, because within that shape is a small pocket called the **active site**.

The active site is where the substrate of the enzyme fits at the start of a reaction. Different substrates have different 3D shapes, and different enzymes have active sites of different shapes. This explains why every enzyme can only work with **specific** substrates that fit the active site.



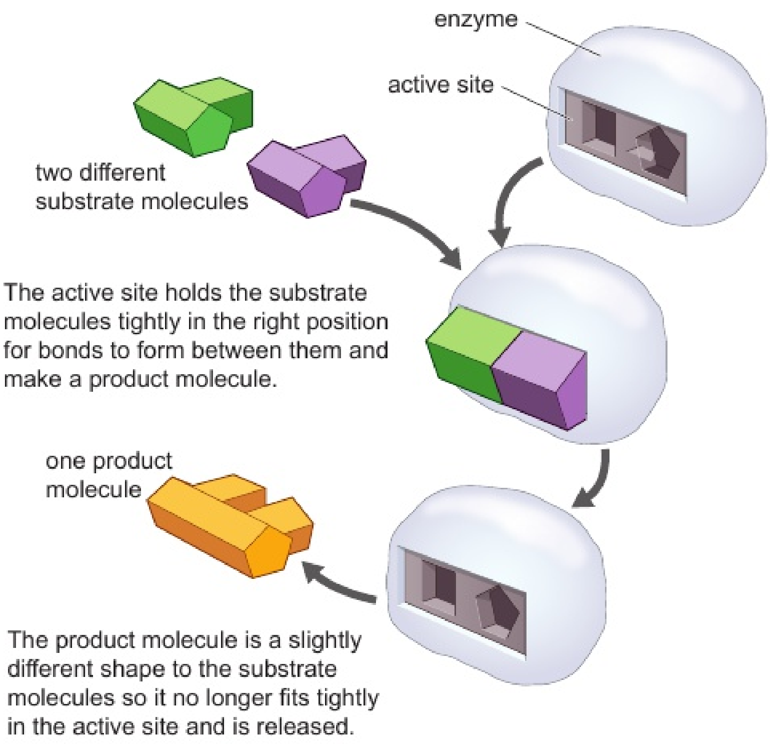
B Glucose is the substrate for the enzyme hexokinase (blue). The substrate (yellow) fits neatly within the enzyme's active site.

1 What is the active site of an enzyme?

2 Why is the active site a different shape in different enzymes?

3 What is meant by 'enzyme specificity'?

One model of how enzymes work is called the **lock-and-key model**, because of how the enzyme and substrate fit together.


enzyme
active site
two different substrate molecules
The active site holds the substrate molecules tightly in the right position for bonds to form between them and make a product molecule.
one product molecule
The product molecule is a slightly different shape to the substrate molecules so it no longer fits tightly in the active site and is released.

C When substrate molecules are held in the right position in the active site, the bonds between them are more easily broken and formed.

Changes in pH or temperature can affect how the protein folds up, and so can affect the shape of the active site. If the shape of the active site changes too much, the substrate will no longer fit neatly in it. If the active site changes shape too much, the enzyme will no longer catalyse the reaction. We say that the enzyme has been **denatured**.

6 Explain what denaturing of an enzyme means.

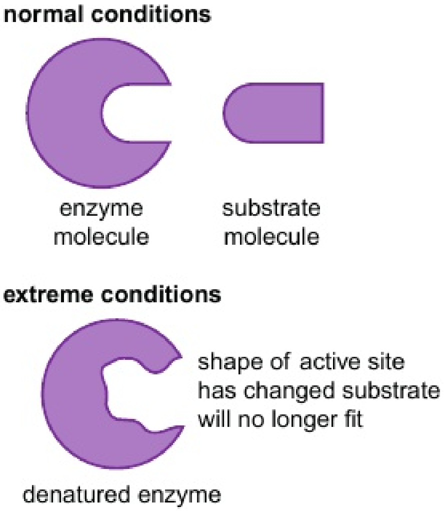
7 Systems in humans keep our body temperatures constant. Using your knowledge of enzymes, explain why this is important.

Exam-style question

Describe how the active site works in an enzyme. *(2 marks)*

4 Explain why amylase does not break down proteins.

5 Use the lock-and-key model to suggest how an amylase enzyme catalyses the breakdown of starch to small sugar molecules.



D Changes in an enzyme's environment can change the shape of the active site.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Sketch one flowchart to show how an enzyme normally works, and another to show what happens when the enzyme is denatured.

Extend

E1 Sketch labelled diagrams to show the following:

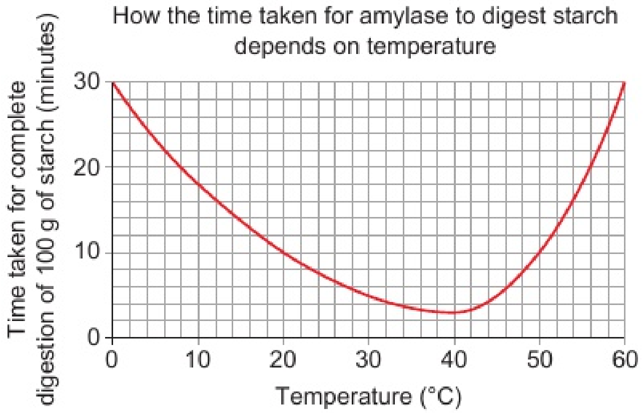
- **a** why enzymes have a particular shape
- **b** why enzymes are specific to a particular substrate
- **c** what happens when an enzyme is denatured.

CB1g Enzyme activity

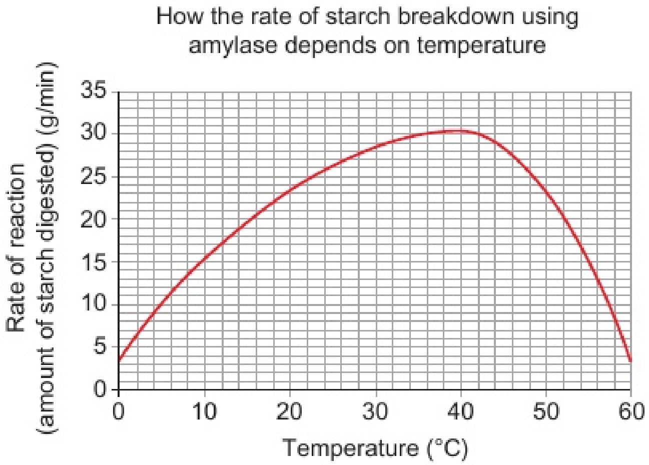
Specification reference: B1.9; B1.11

Progression questions

- How is enzyme activity affected by temperature, pH and substrate concentration?
- How do you calculate the rate of enzyme activity?
- Why is enzyme activity affected by temperature, pH and substrate concentration?



A results from experiments at different temperatures combined on to one graph



B the data in graph A shown as a rate of reaction graph

6th **3** **a** Identify the optimum temperature for the enzyme shown in graph B.

7th **b** Explain your answer.

4 Explain why enzymes work more slowly when the temperature is:

9th **a** below the optimum

9th **b** above the optimum.

Enzymes are affected by the conditions in their surroundings. The results of a series of experiments that measure the time taken for an enzyme to complete the breakdown of a substrate at different temperatures can be combined to produce a graph.

6th **1** Use graph A to identify how long it took for the complete breakdown of starch at the following temperatures:

a 10 °C **b** 40 °C **c** 50 °C.

7th **2** Suggest an explanation for the difference in reaction rates at 40 °C and 50 °C.

Graph A can be converted to a graph showing the rate of reaction by calculating the amount of substrate broken down or product formed in a given time. For example, graph A shows that, at 30 °C, 100 g of starch was broken down in 5 min. The mean rate of reaction was:

$$\frac{100}{5} = 20 \text{ g/min}$$

Converting the values in graph A in this way gives graph B.

Why does graph B have this shape?

- As the temperature increases, molecules move faster. Higher speeds increase the chance of substrate molecules bumping into enzyme molecules and slotting into the active site.
- However, when the temperature gets too high, the shape of the enzyme molecule starts to change. The amount of change increases as the temperature increases. So it becomes more and more difficult for a substrate molecule to fit into the active site.

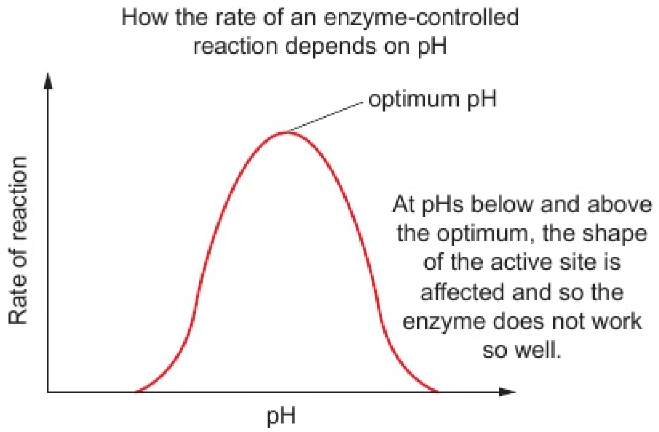
The temperature at which an enzyme works fastest is called its **optimum temperature**.

Did you know?

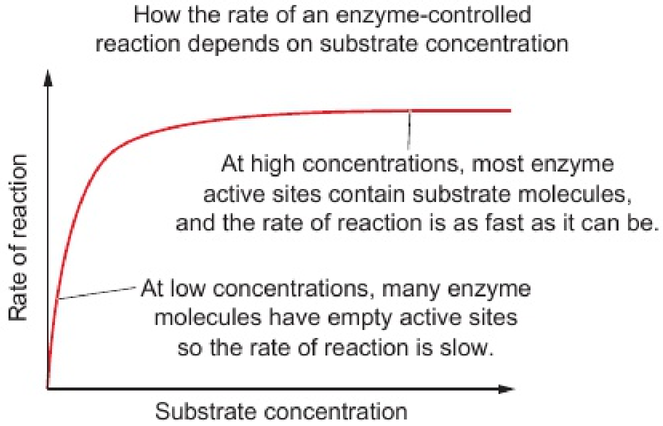
Many human enzymes have an optimum temperature of around 37 °C.

Enzymes are now used in many processes in industry. Some industrial processes take place at high temperatures, so the search for new enzymes that have a high optimum temperature is important.

Some other factors that affect the rate of an enzyme-controlled reaction are pH and the concentration of the substrate, as shown in graphs D and E.



D the effect of pH on the rate of an enzyme-controlled reaction



E the effect of substrate concentration on the rate of an enzyme-controlled reaction

9th **6** Explain the effect of substrate concentration on the rate of an enzyme-controlled reaction.

9th **7** The pH in the stomach is about 2, but in the small intestine it is about 6. Explain why different protease enzymes are found in the two digestive organs.

Exam-style question

The enzyme pepsin digests proteins. Pepsin is denatured at pH 8. Explain what this means. *(2 marks)*

C The bacterium *Thermus aquaticus* was discovered growing in this hotspring pool, which is at about 70 °C.

8th **5** **a** Sketch a graph to show the effect of pH on the enzyme pepsin, which has an **optimum pH** of 2.

9th **b** Annotate your sketch to explain the shape.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Close the book, then sketch and annotate a graph to show how temperature affects the rate of an enzyme-controlled reaction.

Extend

E1 A manufacturer is testing several high-temperature cellulase enzymes to break down plant cell walls in plant waste used for making biofuels. Suggest how the manufacturer might carry out the test and how they would decide which is the best enzyme for this process.

CB1g Core practical – pH and enzymes

Specification reference: B1.10

Aim

Investigate the effect of pH on enzyme activity.

A Only microorganisms that can tolerate highly acidic conditions can live in the water from some mine workings.

Metal ores are rocks that contain valuable metal compounds. Waste water from metal ore mines is often highly acidic and contains small amounts of toxic metals. Mining companies are looking for microorganisms that can live in this water and remove the metals (a process called bioleaching). This will not only reduce pollution, but also help to recover more metal from a mine. Organisms that can live in these environments must have enzymes with an optimum pH that is highly acidic.

Your task

You are going to find the optimum pH of an enzyme. In this case, you are going to use the enzyme amylase, which digests starch. You are going to measure the time taken for the enzyme to break down its substrate at different pHs. Then you will plot the results on a graph. The shortest time taken to digest the substrate indicates the optimum pH for the enzyme.

Method

Wear eye protection.

A Set up heating apparatus using a tripod, gauze, heat-resistant mat, Bunsen burner and large beaker half-filled with water. Heat the water to a temperature of 40 °C, and then use the collar on the Bunsen burner to produce a flame that keeps the water at this temperature. Check that the temperature is being kept constant for a couple of minutes before you start step D.

B Place one drop of iodine solution into each depression of a well tray (dimple tile).

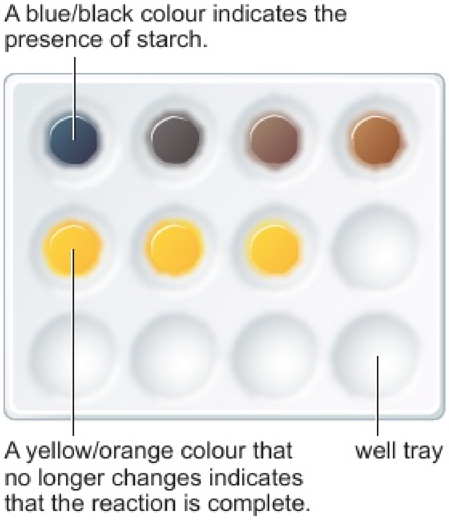
C Measure 2 cm^3 of amylase solution into a tube.

D Add 1 cm^3 of a solution with a particular pH into the tube.

E Add 2 cm^3 of starch solution to the tube and place it carefully into the water bath. Start the stop clock. Stir the mixture.

F Every 20 seconds, take a small amount of mixture and place one drop of it into a fresh drop of iodine solution. Stop testing when the iodine solution stops changing colour.

G Repeat the experiment using a different pH solution in step D.


A blue/black colour indicates the presence of starch.
A yellow/orange colour that no longer changes indicates that the reaction is complete.
well tray

B iodine solution is used to indicate the presence of starch

Exam-style questions

1 State what is meant by the substrate of an enzyme. *(1 mark)*

2 State what is meant by the optimum pH of an enzyme. *(1 mark)*

3 Explain why an enzyme catalyses the reaction of only one particular substrate. *(2 marks)*

4 Explain why changing the pH affects the activity of an enzyme. *(2 marks)*

5 State the colour of iodine solution before and after it is in contact with starch. *(2 marks)*

6 In the experiment described on the previous page, explain why the iodine solution eventually stops changing colour when mixed with the solution. *(2 marks)*

7 **a** Explain why the enzyme reaction is carried out in a water bath in step A of the method on the previous page. *(2 marks)*

b Describe an alternative way of doing this. *(1 mark)*

c Explain whether your alternative suggestion would improve the experiment. *(2 marks)*

8 Catalase is an enzyme that breaks down hydrogen peroxide into water and oxygen. Some students are investigating the effect of pH on this enzyme-controlled reaction by collecting the oxygen. One suggestion is to bubble the gas through water and collect it in an upturned measuring cylinder full of water. Another suggestion is to collect the gas in a gas syringe.

a Explain which method of gas collection you would use. *(2 marks)*

b Explain how the students should measure the pH in their investigation. *(2 marks)*

c Table C shows the results from the students' investigation. Draw a graph to display the results. *(3 marks)*

d Identify the anomalous result and suggest a reason for the error. *(2 marks)*

e Calculate the average rate of reaction (average volume of oxygen produced per minute) at pH 6. *(1 mark)*

9 Scientists working on bioleaching are interested in an enzyme called glucose oxidase, which is found in many microorganisms. Graph D shows the results from an investigation into the effect of pH on the rate of activity of glucose oxidase from two different types of bacteria.

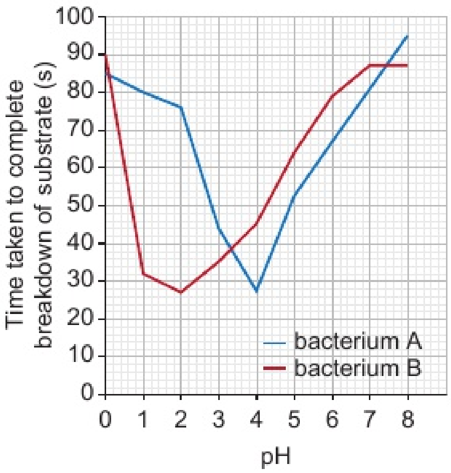
a What is the optimum pH for glucose oxidase from each type of bacterium? *(2 marks)*

b Explain which enzyme is more active at pH 5. *(1 mark)*

c Explain which bacterium might be more useful for bioleaching mine water. *(2 marks)*

Time (min)	Volume of O_2 released (cm^3)	
	at pH 3	at pH 6
1	1.4	1.6
2	2.7	3.2
3	4.2	5.6
4	5.9	5.7
5	6.6	8.4
6	8.4	10.6

C results for an investigation of the effect of pH on an enzyme-controlled reaction



D Graph to show the effect of pH on glucose oxidase. This enzyme catalyses a reaction in which glucose is broken down to form hydrogen peroxide. Hydrogen peroxide can help obtain metals from mine waste.

CB1h Transporting substances

Specification reference: B1.15; B1.17

Progression questions

- What is the difference between diffusion and osmosis?
- How do cells move substances against a concentration gradient?
- How do you calculate a percentage change in mass?

A an experiment to assess body odour

1 Explain why smells spread.

2 **a** A dish of perfume is put at the front of a lab. Describe the perfume's concentration gradient after 5 minutes.

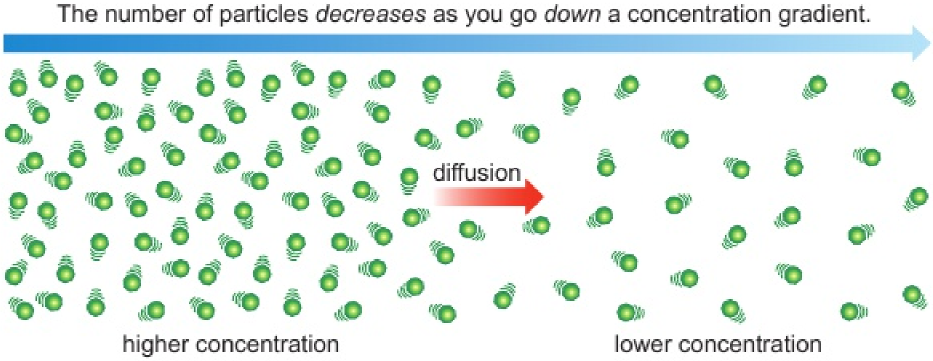
b Describe the overall movement of the perfume molecules.

3 Muscle cells in the leg use up oxygen but are surrounded by a fluid containing a lot of oxygen. Explain why oxygen moves into the cells.

Bacteria living on your body cause body odour. The smelly substances they produce are released into the air and reach our noses.

Smells spread by **diffusion**. Particles in gases and liquids are constantly moving past each other in random directions. This causes an overall movement of particles from where there are more of them (a higher **concentration**) to where there are fewer (a lower concentration).

A difference between two concentrations forms a **concentration gradient**. Particles diffuse *down* a concentration gradient. The bigger the difference between concentrations, the steeper the concentration gradient and the faster diffusion occurs.


The number of particles *decreases* as you go *down* a concentration gradient.
diffusion
higher concentration
lower concentration

B diffusion occurs down a concentration gradient

Diffusion allows small molecules (such as oxygen and carbon dioxide) to move into and out of cells.

Osmosis

A membrane that allows some molecules through it and not others is **partially permeable** (or **semi-permeable**).

Cell membranes are semi-permeable and trap large soluble molecules inside cells, but water molecules can diffuse through the membrane. If there are more water molecules in a certain volume on one side of the membrane than the other, there will be an overall movement of water molecules from the side where there are more water molecules (a more dilute **solute** concentration) to the side where there are fewer water molecules (a more concentrated solution of solute). This diffusion of small molecules of a **solvent**, such as water, through a semi-permeable membrane is called **osmosis**. The overall movement of solvent molecules will stop when the concentration of solutes is the same on both sides of a membrane.

4 **a** In diagram C, in which direction will water flow, X to Y or Y to X?

b Explain why this flow occurs.

5 Red blood cells contain many solute molecules. Explain why red blood cells burst if put in pure water.

Osmosis can cause tissues to gain or lose mass. To calculate the mass change:

- work out the difference between the mass of tissue at the start and at the end (final mass – initial mass)
- divide this difference by the initial mass
- multiply by 100.

So, percentage change in mass $= \dfrac{\text{(final mass – initial mass)}}{\text{initial mass}} \times 100$

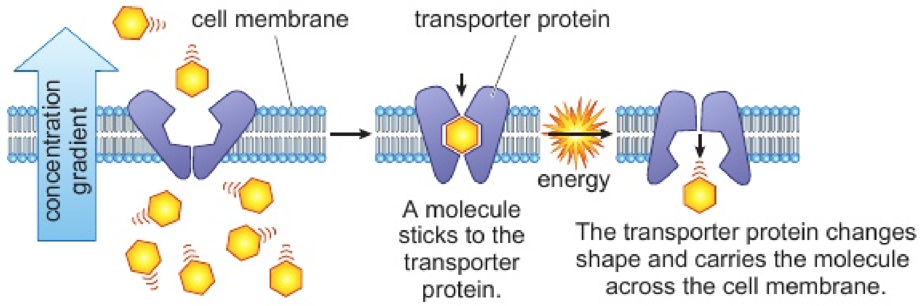
A negative answer is a percentage *loss* in mass.

6 An 8 g piece of potato is left in water for an hour. Its mass becomes 8.5 g. Calculate the percentage change in mass.

Active transport

Cells may need to transport molecules *against* a concentration gradient or transport molecules that are too big to diffuse through the cell membrane. They can do this using **active transport**.

This process is carried out by transport proteins in cell membranes. The transport proteins capture certain molecules and carry them across the cell membrane. This is an active process and so requires energy. Osmosis and diffusion are **passive** processes, so do not require an input of energy.

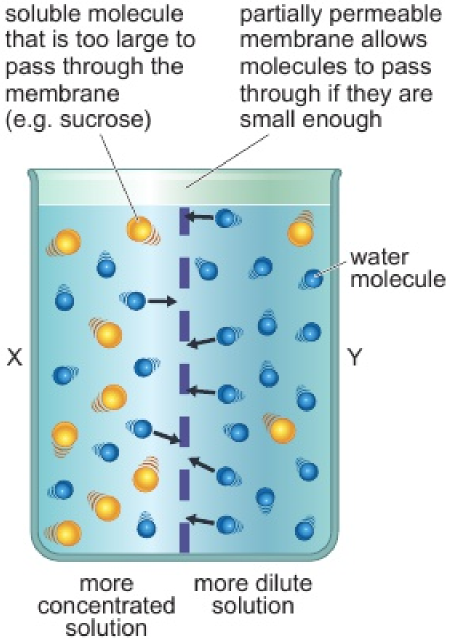

cell membrane
transporter protein
concentration gradient
energy
A molecule sticks to the transporter protein.
The transporter protein changes shape and carries the molecule across the cell membrane.

D active transport

8 Explain how cells that carry out a lot of active transport would be adapted to their function.

Exam-style question

Explain why a slice of potato will decrease in mass if it is placed in a concentrated sugar solution. *(2 marks)*


soluble molecule that is too large to pass through the membrane (e.g. sucrose)
partially permeable membrane allows molecules to pass through if they are small enough
water molecule
X
Y
more concentrated solution
more dilute solution

C In osmosis, a solvent flows from a dilute solution of a solute to a more concentrated one.

7 Look at diagram D. Explain why active transport is needed to move the molecules.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 A small number of sugar molecules are in your small intestine. Describe how they will be absorbed into cells in the small intestine and why they need to be absorbed in this way.

Extend

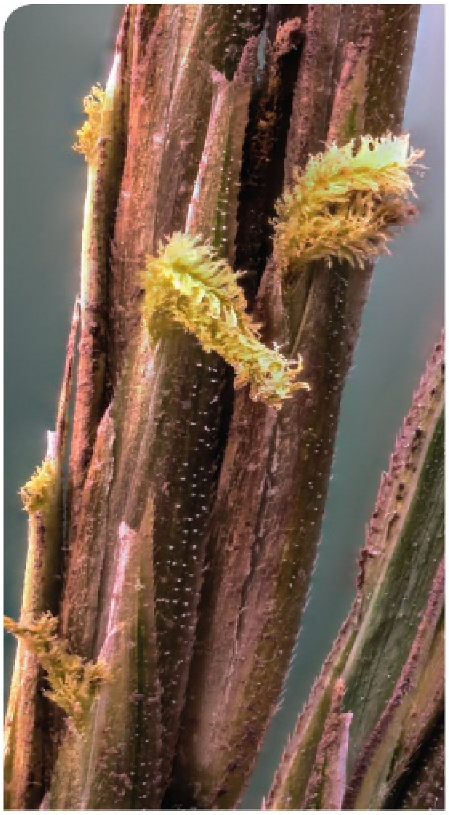
E1 Sorbitol is a sweet-tasting substance that is not broken down or absorbed by the body. It is used in some sugar-free sweets. Explain why eating too many of these sweets can cause diarrhoea.

CB1h Core practical – Osmosis in potato slices

Specification reference: B1.16

Aim

Investigate osmosis in potatoes.



A The tiny white crystals on this cord grass are salt released from glands on the surface of the leaves.

Most land plants die if flooded with sea water. Usually the concentration of mineral salts in the soil is less than inside the roots, so water moves into the root from the soil by osmosis. If the soil contains a high concentration of salts then osmosis occurs out of the root, into the soil. Without sufficient water, plants die. Some plants, called halophytes, are adapted to live in salty areas. Their roots take in large amounts of salts from the soil, which helps osmosis to continue from the soil into the plant. Halophytes get rid of the extra salt they absorb in various ways.

Your task

You are going to measure osmosis in plant tissue, by comparing the mass of the tissue before and after soaking in sucrose solution. Sucrose is used because the molecules are too large to diffuse through cell membranes. The change in the mass of the tissue shows how much water is absorbed or lost. You can work out the solute concentration of the plant tissue from repeating the experiment with solutions of different concentrations.

When comparing different pieces of tissue, remember to calculate the percentage change in mass of each piece.

Method

A Label a separate boiling tube with the sucrose concentration of each solution you will test. Place all the tubes in a rack.

B Cut similar-sized pieces of potato, enough for one per tube. (Make sure they fit in a tube.)

C Blot each potato piece dry, measure and record its mass, and put it in an empty tube.

D Fill each tube with the solution of the appropriate concentration. Ensure you cover the potato with the solution.

E After at least 15 minutes, remove each potato piece and blot it dry. Measure and record its mass again.

Exam-style questions

1 Define the term 'osmosis'. *(1 mark)*

2 Use the idea of osmosis to explain why most plants in salty soil would have problems absorbing water through their roots. *(2 marks)*

3 Explain how halophyte roots are adapted to help them absorb water from salty soil. *(2 marks)*

4 **a** State which variables have been kept the same in the method on the previous page. *(1 mark)*

b Explain the importance of controlling these variables. *(2 marks)*

5 Write an equipment list for the method shown on the previous page. *(2 marks)*

6 Explain how you would work out a suitable range of sucrose concentrations for the solutions in the potato experiment. *(2 marks)*

7 Give a reason why you should calculate percentage change in mass when comparing results. *(1 mark)*

8 State one way to improve the method for the potato experiment so that you could be more certain of the results. *(1 mark)*

9 Table B shows the results from an experiment similar to the one described in the method.

a For each solution, calculate the gain or loss in mass of the potato piece. *(2 marks)*

b For each solution, calculate the percentage change in mass of the potato. *(2 marks)*

c Give a reason for the result from tube A. *(1 mark)*

d Explain the results from tubes B–D. *(2 marks)*

e Use the results to give the possible solute concentration of potato tissue, giving a reason for your answer. *(2 marks)*

f Describe how the method could be adapted to give a more accurate answer to part **e**. *(1 mark)*

10 Graph C shows the results of an experiment comparing osmosis in tissue from a halophyte plant and a potato in the same solution.

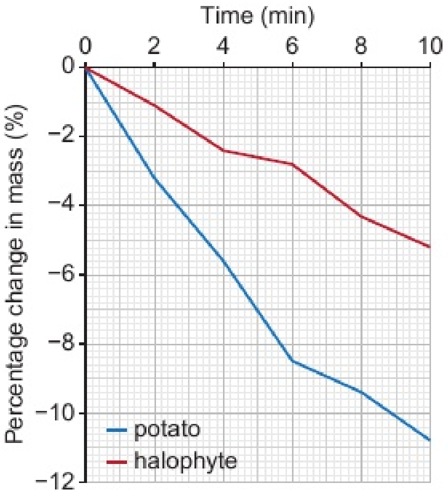
a Identify, with a reason, which tissue lost water fastest over the first five minutes. *(2 marks)*

b Explain why it lost water faster than the other tissue. *(2 marks)*

c Calculate the average rate of change in mass over the first four minutes for the potato. *(1 mark)*

Tube	A	B	C	D
Sucrose concentration (%)	0	10	30	50
Mass of potato at start (g)	4.81	5.22	4.94	4.86
Mass of potato at end (g)	4.90	4.96	4.39	3.69

B the effect of sucrose concentration on the change in mass of potato (concentration 0 is distilled water)



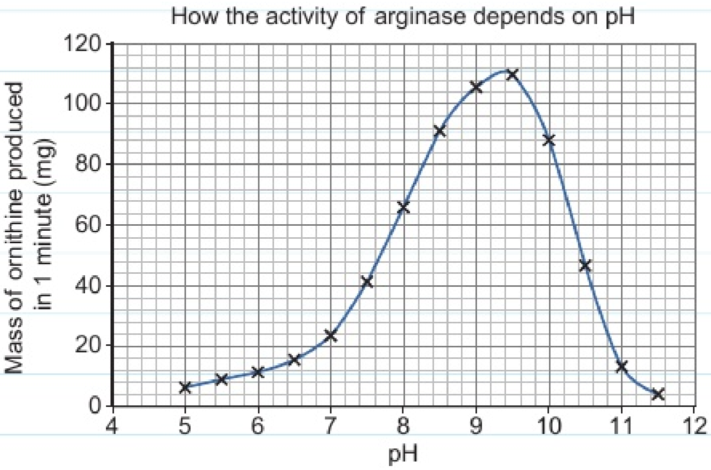
C change in mass of a halophyte plant and potato in the same solution

Arginase

Unused amino acids are broken down into a waste substance called urea. One enzyme involved in the process is called arginase, which catalyses this reaction:

arginine + water → ornithine + urea

In an experiment, the activity of arginase was tested at different pHs. The graph below shows the results. Explain the effect of pH on arginase. (6 marks)



A

Student answer

The pH affects arginine [1] *and makes it make the reaction faster or slower. It shows that the enzyme is best in high pH* [2].

[1] The name of the enzyme is arginase (the substrate is arginine). It is very important to use the correct scientific names.

[2] The answer correctly says that the enzyme is more active at higher pHs.

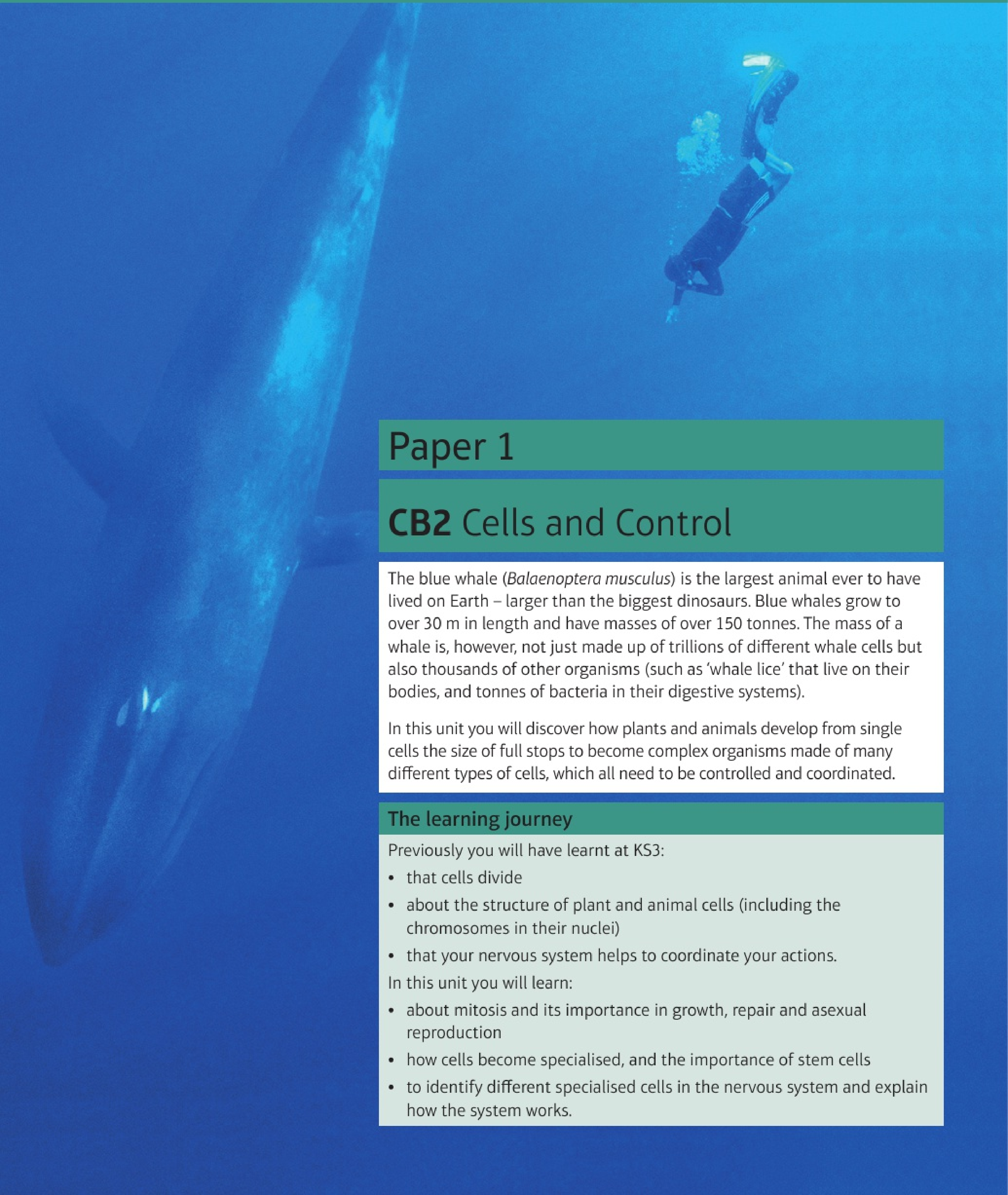
Verdict

This is a weak answer. It only contains one correct fact and there is no explanation about why pH has an effect on the enzyme.

The key word in the question is 'explain'. The answer could be improved by explaining the link between the shape of the graph and how the enzyme works (i.e. the enzyme works best at the optimum pH because this is when the active site has the best shape for the substrate to fit into it). A really good answer would also have used data from the graph (e.g. pointing out that the optimum pH is 9.4).

Exam tip

It may help to note down some key facts that you know about the topic before you write your answer. Cross out your notes when you have finished writing.



Paper 1

CB2 Cells and Control

The blue whale (*Balaenoptera musculus*) is the largest animal ever to have lived on Earth – larger than the biggest dinosaurs. Blue whales grow to over 30 m in length and have masses of over 150 tonnes. The mass of a whale is, however, not just made up of trillions of different whale cells but also thousands of other organisms (such as 'whale lice' that live on their bodies, and tonnes of bacteria in their digestive systems).

In this unit you will discover how plants and animals develop from single cells the size of full stops to become complex organisms made of many different types of cells, which all need to be controlled and coordinated.

The learning journey

Previously you will have learnt at KS3:

- that cells divide
- about the structure of plant and animal cells (including the chromosomes in their nuclei)
- that your nervous system helps to coordinate your actions.

In this unit you will learn:

- about mitosis and its importance in growth, repair and asexual reproduction
- how cells become specialised, and the importance of stem cells
- to identify different specialised cells in the nervous system and explain how the system works.

CB2a Mitosis

Specification reference: B2.1; B2.2; B2.3; B2.4

Progression questions

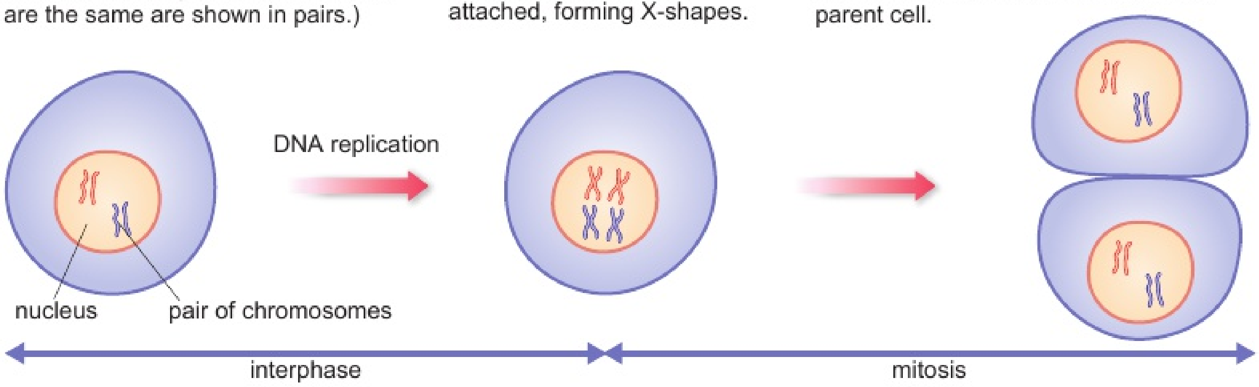
- Why is mitosis important?
- What happens in the different stages of mitosis?
- How do cancer tumours occur?

Every living thing needs to be able to grow and to repair itself in order to stay alive. In organisms that are made of many cells (**multicellular** organisms) the processes of growth and repair require new cells. These are produced in a process called the **cell cycle**.

This diploid cell has two sets of chromosomes – one blue and one red in each set. (Chromosomes that are the same are shown in pairs.)

Each chromosome is copied and the copies remain attached, forming X-shapes.

The copies of the chromosomes separate and each daughter cell ends up with the same number of chromosomes as the parent cell.



A During the cell cycle two identical daughter cells are formed from a parent cell.

The nuclei of human body cells contain two copies of each of 23 types of chromosome, making 46 in all. Cells with two copies of each chromosome (two sets of chromosomes) are **diploid**. Gametes (sex cells) contain one copy of each type of chromosome and are **haploid**.

There are two phases in the cell cycle, the first of which is **interphase**. In this phase the cell makes extra sub-cellular cell parts (e.g. mitochondria). **DNA replication** (copying) also occurs, to make copies of all the chromosomes. The copies of the chromosomes stay attached to each another, making the chromosomes look like Xs.

The next phase of the cell cycle is cell division or **mitosis**. The cell splits to form two **daughter cells**, which are both identical to the parent cell. Mitosis occurs in a series of continuous stages, shown in diagram B.

Did you know?

Damaged human organs cannot regrow … apart from the liver. Liver transplants are often done using part of a liver because the transplanted piece of liver grows by mitosis to form a full-sized liver. The liver pieces for transplants can be taken from living donors because livers grow back.

1 Give the name of one diploid and one haploid cell in the body of a mammal.

2 Alligators have eight types of chromosome. How many chromosomes are in a diploid alligator cell?

3 Why is DNA replication important in interphase?

4 Why must the number of mitochondria double in a cell during interphase?

5 Draw a table to show what happens in each stage of mitosis.

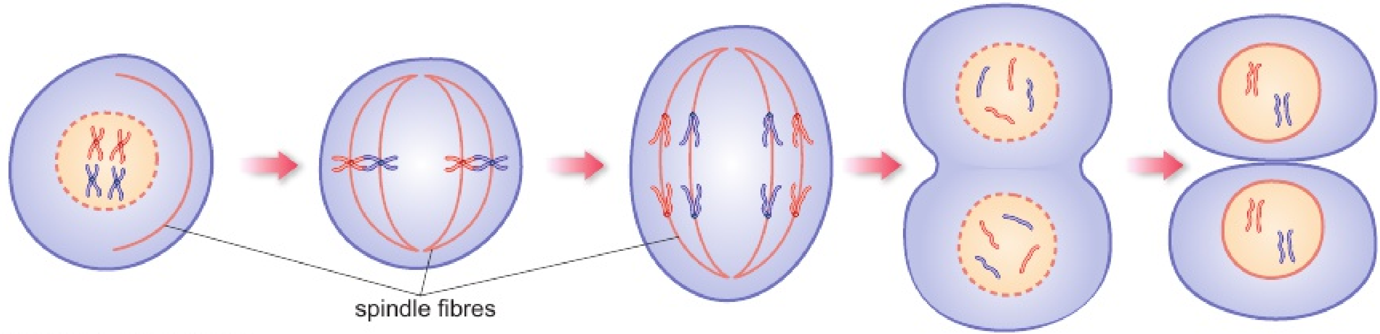
In **prophase** the nucleus starts to break down and **spindle fibres** appear.

By the end of **metaphase**, the chromosomes are lined up on the spindle fibres across the middle of the cell.

The chromosome copies are separated and moved to either end of the cell on the spindle fibres. This is **anaphase.**

In **telophase** a membrane forms around each set of chromosomes to form nuclei.

A cell surface membrane forms to separate the two cells during **cytokinesis.** Cell walls form in plant cells.



B the stages of mitosis

Asexual reproduction

Some organisms can reproduce using just one parent. This **asexual reproduction** produces offspring that are **clones**, which means that their cells have the same chromosomes as the parent (they are genetically identical). So, asexual reproduction relies on mitosis. Strawberry plants, for example, reproduce asexually using stems that grow along the ground, called runners, and potatoes use tubers. Some animals, such as aphids, can also reproduce asexually. Asexual reproduction is much faster than sexual reproduction because organisms do not need others for reproduction. However, sexual reproduction produces variation and asexual reproduction does not.

C Asexual reproduction is rare in larger animals, but female Komodo dragons can reproduce asexually.

D plantlets produced by asexual reproduction growing on the leaf margins of *Kalanchöe* plant

Growth of cancer tumours

Normal cells only divide when they need to. Changes in cells can, however, sometimes turn them into **cancer cells**, which means that they undergo uncontrollable cell division. This rapid cell division produces growing lumps of cells called **tumours** that can damage the body and can result in death.

Exam-style question

Explain why sperm cells cannot be produced using the cell cycle. *(2 marks)*

8th **6** Why is each plantlet in photo D a clone?

7th **7** Daughter cells produced by mitosis are said to be 'genetically identical' to the parent cell. Explain what this means.

8th **8** Why does asexual reproduction rely on mitosis?

9 A rose plant has a 'crown gall tumour' on its stem.

8th **a** What would you expect this to look like?

9th **b** Explain how this occurs.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a flow chart to show mitosis.

Extend

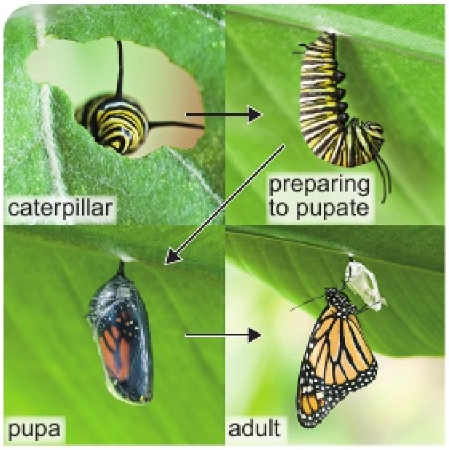
E1 Explain why mitosis is important for the reproduction of organisms if there are very few members of the opposite sex in an area.

CB2b Growth in animals

Specification reference: B2.5; B2.6; B2.7

Progression questions

- Which processes in animals result in growth and development?
- How are percentile charts used to monitor growth in children?
- Why is cell differentiation important in animals?



A During the pupal stage, a caterpillar digests itself! Only some cells remain, but using cell division and differentiation these cells produce all the specialised cells in the adult butterfly.

Growth is an increase in size as a result of an increase in number or size of cells. The number of cells increases due to cell division by mitosis. Growth can be recorded by taking measurements over time, such as of length or mass.

1 **a** Suggest how you could measure the growth of a kitten.

b Explain your answer.

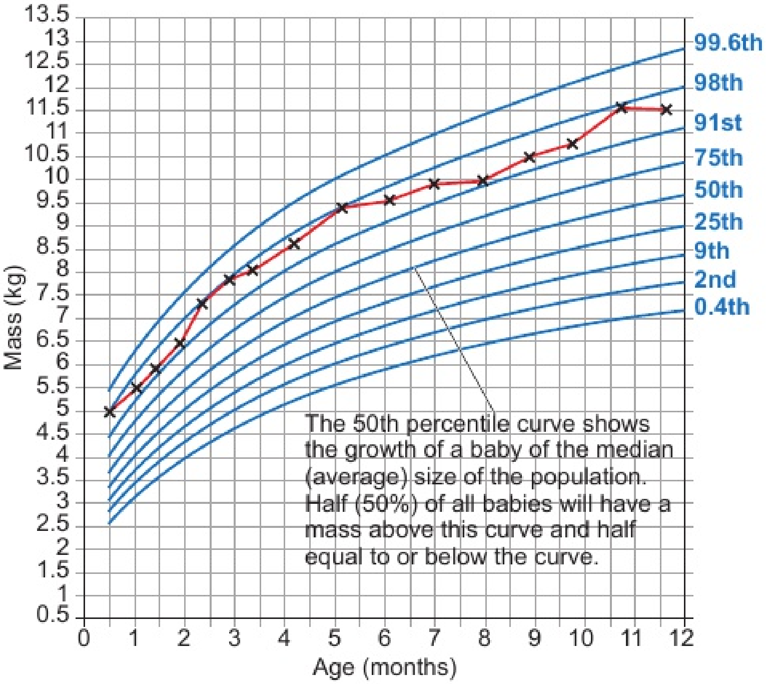
2 **a** Your mass increases when you take in food and drink. Is this an example of growth?

b Explain your answer.

The growth of human babies is regularly checked by measuring them, including mass and length. The measurements are checked on charts to show how well a baby is growing compared to others at the same age.

These charts were created by measuring a very large number of babies. The measurements were divided into 100 groups. When divided like this we can find out what percentage of readings are below a certain value, or **percentile**. For example, 25 per cent of babies will have masses below the 25th percentile line, whereas 75 per cent of babies will be below the 75th percentile line. So, if the 25th percentile for an 8-month-old baby's mass is 8 kg then 25 per cent of 8-month-old babies have a mass below this value.

The curved lines (see graph B) show the rate of growth of a baby who stays at exactly the same percentile within the population. Most babies don't grow at the same rate all the time, so plotting their mass helps to identify whether they are growing normally. Although rate of growth may vary from week to week, a baby should remain near the same percentile curve as it gets older.



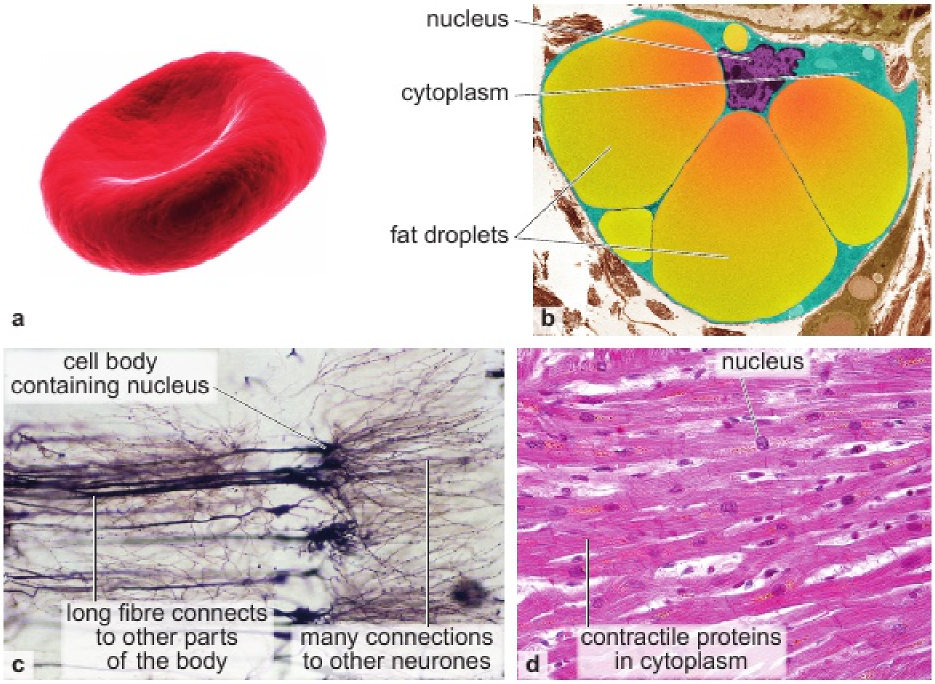
B Percentile growth curves for UK baby boys from 2 weeks to 1 year, for mass. The red line that has been plotted on the curves shows the growth of one baby.

Did you know?

Growth is not charted for the first two weeks of life because babies often lose weight as they adjust to feeding from the breast or bottle rather than getting their nutrients from the placenta.

Cell differentiation

Although all animals develop from a single cell, not all the cells in their bodies are the same. Cells produced by mitosis are the same as the cell from which they were formed. However, the new cells may then change in different ways, so they become specialised for different functions. The process that changes less specialised cells into more specialised ones is called **differentiation**.


nucleus
cytoplasm
fat droplets
a
b
cell body containing nucleus
long fibre connects to other parts of the body
many connections to other neurones
c
nucleus
contractile proteins in cytoplasm
d

C Here are some specialised human cells. (a, top left) A red blood cell has no nucleus, allowing more space for red haemoglobin molecules (which carry oxygen). It also has a large surface area (allowing oxygen to diffuse in and out more quickly). (b, top right) The cytoplasm of fat cells is filled with large fat droplets. The fat is stored until the body needs energy. (c, bottom left) Nerve cells (neurones) have a long fibre that carries electrical impulses around the body and many connections to other neurones. (d, bottom right) Muscle cells contain special contractile proteins that can shorten the cell.

5 **a** Describe a special feature of a fat cell.

b Explain how a red blood cell is specialised for its function of carrying oxygen around the body.

6 **a** Describe two kinds of specialised cells you would expect to find in a butterfly.

b Explain your choices and predict the adaptations that the cells have.

Exam-style question

Explain why percentile curves are used to measure the growth of babies.

(2 marks)

3 Look at graph B.

a What is the value of the 50th percentile for mass in a 6-month-old baby boy?

b How much should the mass of a baby boy in the 50th percentile increase between 3 and 9 months of age?

4 Does the baby plotted on graph B (the red line) show healthy growth? Explain your answer.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe how a single fertilised human egg cell develops into the billions of different cells in a human adult.

Extend

E1 What are the advantages and disadvantages of using percentile curves to assess the growth and development of a young baby?

CB2c Growth in plants

Specification reference: B2.5; B2.6

Progression questions

- How do plants grow?
- How are some specialised plant cells adapted to their function?
- Why is cell differentiation important in plants?

A El Árbol del Tule is a Montezuma cypress. In 1998, its girth was 36 m round the trunk at 1.5 m above the ground.

6th **1** What is a plant meristem?

2 Describe what happens in the following zones of a plant shoot.

6th **a** zone of division

6th **b** zone of elongation

7th **c** zone of differentiation

5th **3** **a** Are the dividing cells in a plant meristem all similar to or different from each other?

7th **b** Explain your answer.

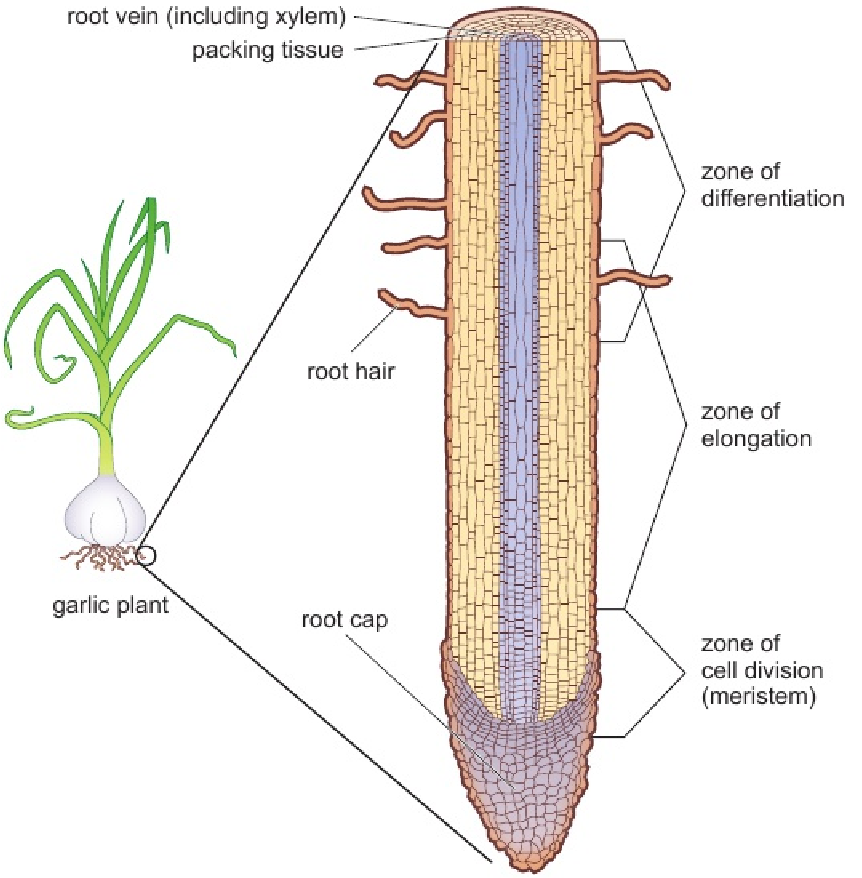
4 Diagram B shows root hair cells, which absorb water and mineral salts from the soil.

6th **a** How are the cells adapted for this function?

7th **b** Explain how their adaptation helps them to carry out their function well.

Guinness World Records has two entries for 'the world's largest living tree'. El Árbol del Tule has the largest girth (the length around its trunk) and General Sherman has the greatest volume.

A group of cells near the end of each shoot and root allows plants to continue growing throughout their lives. These groups of cells are called **meristems**. The cells in meristems divide rapidly by mitosis. Many of the cells produced then increase in length (**elongation**), and **differentiate** into specialised cells that have different functions.

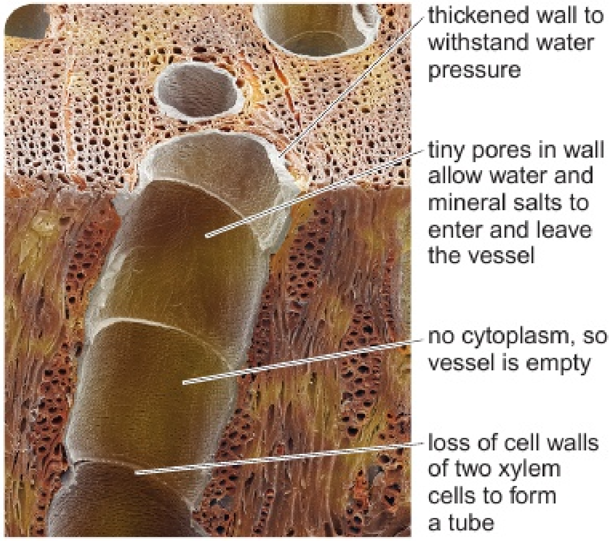


B The zones of an onion root tip where cells divide, elongate and differentiate into specialised cells. (Note: colour has been added to help identify different tissues.)

There are many kinds of specialised plant cell, such as **root hair cells** and **xylem cells**. Each kind of cell has certain features so that it is adapted to its function. The many different kinds of specialised cell in a plant allow the plant to carry out many different processes effectively.

5 Photo C shows xylem vessels that carry water throughout the plant. Describe how xylem vessels are specialised to carry out this function well.

6 Explain why plants need root hair cells and xylem vessels.


thickened wall to withstand water pressure
tiny pores in wall allow water and mineral salts to enter and leave the vessel
no cytoplasm, so vessel is empty
loss of cell walls of two xylem cells to form a tube

C A xylem vessel is a long tube formed from many dead xylem cells.

Did you know?

About 400 dm^3 of water is absorbed from the soil, passes through the xylem and evaporates from the leaves of a large oak tree every day.

There are many different ways of measuring growth in plants, including height, leaf surface area and mass. Percentage changes are often worked out for these values and can be calculated using this formula:

$$\frac{\text{final value} - \text{starting value}}{\text{starting value}} \times 100\%$$

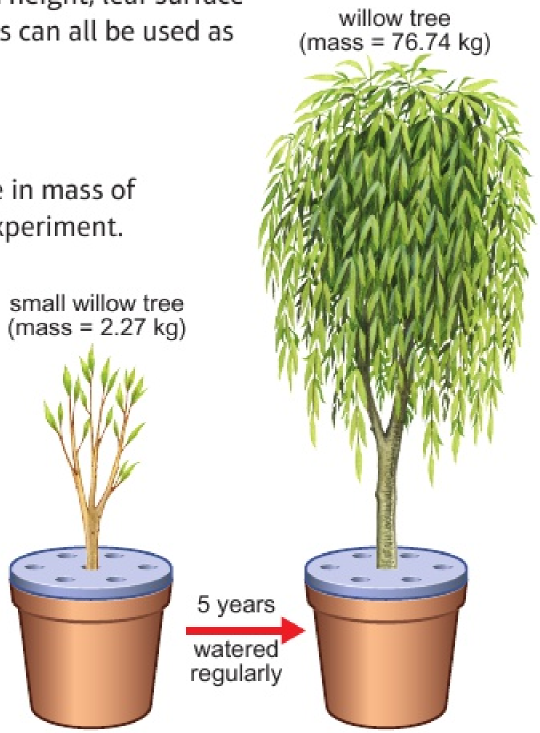
7 Use the definition of 'growth' on page 22 to explain why increases in height, leaf surface area, tree girth and mass can all be used as measures of growth.

8 Look at diagram D.

a Calculate the increase in mass of the tree during the experiment.

b Calculate the percentage increase in mass of the tree over the five years.

9 Palisade cells are plant cells found inside leaves, near the top surface. Their main function is photosynthesis. Suggest how these cells are adapted for this function, and explain your reasoning.


willow tree (mass = 76.74 kg)
small willow tree (mass = 2.27 kg)
5 years
watered regularly

D the results of a growth experiment carried out by Jan Baptista Van Helmont (1580–1644)

Exam-style question

Explain why plant meristem cells contain many ribosomes. *(2 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 The tree in photo A grew from a small seedling. Use bullet points to describe how the seedling increased in size and developed into the tree.

Extend

E1 In the bottom surface of leaves are tiny pores that allow gases to diffuse into and out of the leaf. Each pore is controlled by two guard cells, which can change shape. At night the guard cells lose water to close the pore. During the day they fill with water to open the pore. Suggest one adaptation you would expect to see in guard cells and explain your answer.

CB2d Stem cells

Specification reference: B2.8; B2.9

Progression questions

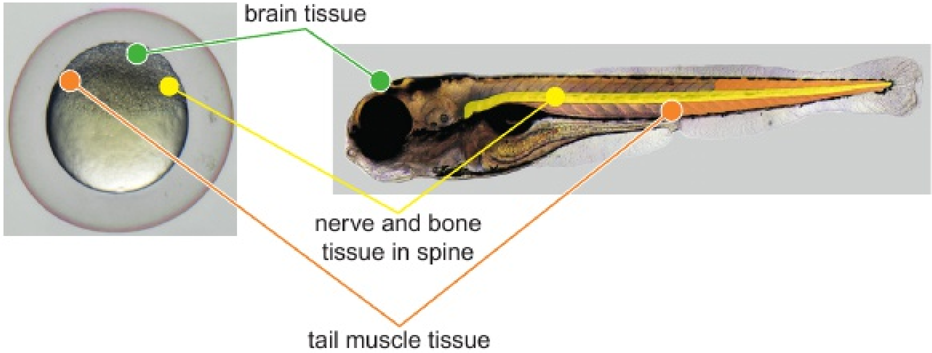
- Where are stem cells found?
- What is the function of stem cells?
- What are the advantages and risks of using stem cells in medicine?

A Geckos are reptiles that are able to grow a whole new tail if it is cut off. Regrowth of many different tissues to make a new organ is rare in adult animals.

Cells that can divide repeatedly over a long period of time to produce cells that then differentiate are called **stem cells**. In plants, these cells are found in meristems (and are sometimes called **meristem cells**).

Plant stem cells are usually able to produce any kind of specialised cell throughout the life of the plant. This is not true for most animals, especially vertebrates.

Animals start life as a fertilised egg cell, which then divides to form an embryo. The cells of an early-stage embryo are **embryonic stem cells** that can produce any type of specialised cell. As the cells continue to divide, the embryo starts to develop different areas that will become the different organs. The stem cells in these areas become more limited in the types of specialised cell they can produce.



B Stem cells in different parts of a zebrafish embryo (on the left) form different tissues as it develops into a young fish.

By the time the young animal is fully developed, the stem cells can usually only produce the type of specialised cell that is in the tissue around them. These are called **adult stem cells** (even if they are in a young animal). The adult stem cells in human tissues allow the tissues to grow and to replace old or damaged cells.

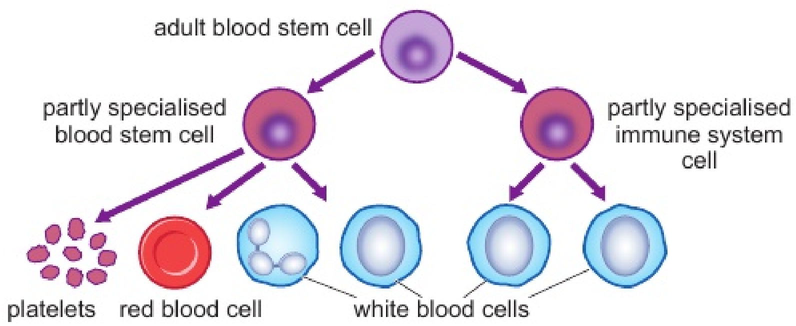
1 **a** State where you can find stem cells in two different plant organs.

b Describe the function of the stem cells in these two plant organs.

2 Stem cells are unspecialised cells. Define the term 'unspecialised'.

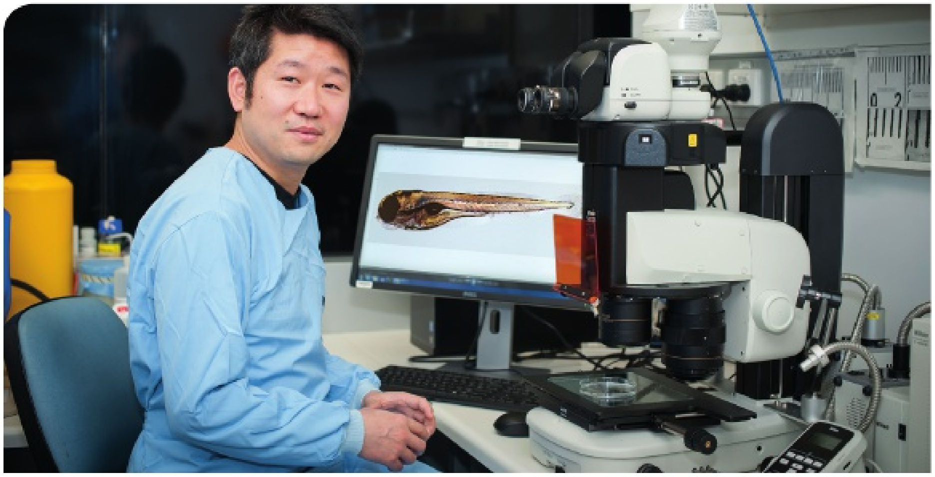
Did you know?

Zebrafish are able to regenerate many parts of their body using stem cells. They can replace their fins, skin, heart tissue, and even brain cells when they are young. This has made them the most important organism in stem cell research.


adult blood stem cell
partly specialised blood stem cell
partly specialised immune system cell
platelets
red blood cell
white blood cells

C Blood stem cells are found in marrow in the middle of long bones (such as the femur). They continue to divide throughout life to produce new blood cells.

Stem cells offer a way of treating many different diseases caused by damaged cells. The first successful human bone marrow transplant was carried out in the late 1950s. Healthy bone marrow from one identical twin was given to the other twin who had a blood disease. Since then, scientists have studied other ways to use adult and embryonic stem cells to treat diseases such as type I diabetes, or to replace damaged cells. This is done by stimulating stem cells to make them produce the specialised cells that are needed and then injecting them into the places they are needed.



D Young zebrafish are transparent. This makes them useful for studying how vertebrate stem cells work and finding out which drugs or treatments might affect stem cells in the body. Successful treatments might then be tried on humans.

There are problems with using stem cells, which scientists are still trying to solve. For example, if stem cells continue to divide inside the body after they have replaced damaged cells, they can cause **cancer**. Another problem is that stem cells from one person are often killed by the immune system of other people that they are put into. This is called **rejection**.

7 Describe two risks of using stem cells to treat disease.

Exam-style question

Describe the role of meristems in plant growth. *(2 marks)*

3 What is the function of stem cells in bone marrow?

4 Explain why blood stem cells only produce blood cells.

5 Compare adult and embryonic stem cells in terms of what they can do, and their functions.

6 Explain how stem cells could be used to help repair damaged heart muscle cells in someone who has had a heart attack.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 a Describe the functions of the different kinds of stem cell in animals and plants.

b Describe one benefit and one risk of using stem cells in medicine.

Extend

E1 In 2014, scientists studying zebrafish discovered that 'buddy' cells are needed to help one type of stem cell become blood stem cells.

a Suggest how this research could lead to new treatments for people with diseases.

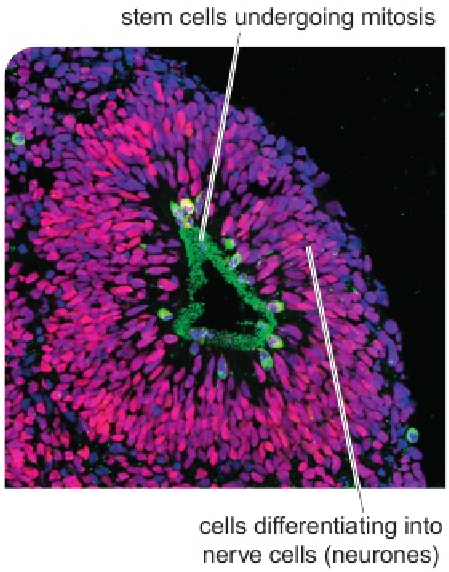
b Suggest what risks must be overcome before these treatments can be given to patients.

CB2e The nervous system

Specification reference: B2.13

Progression questions

- What is the nervous system?
- How does the nervous system allow the body to respond to stimuli?
- How is a sensory neurone adapted to its function?


stem cells undergoing mitosis
cells differentiating into nerve cells (neurones)

A This clump of living brain cells was produced from stem cells and grown in the lab. These clumps can be up to 5 mm in diameter.

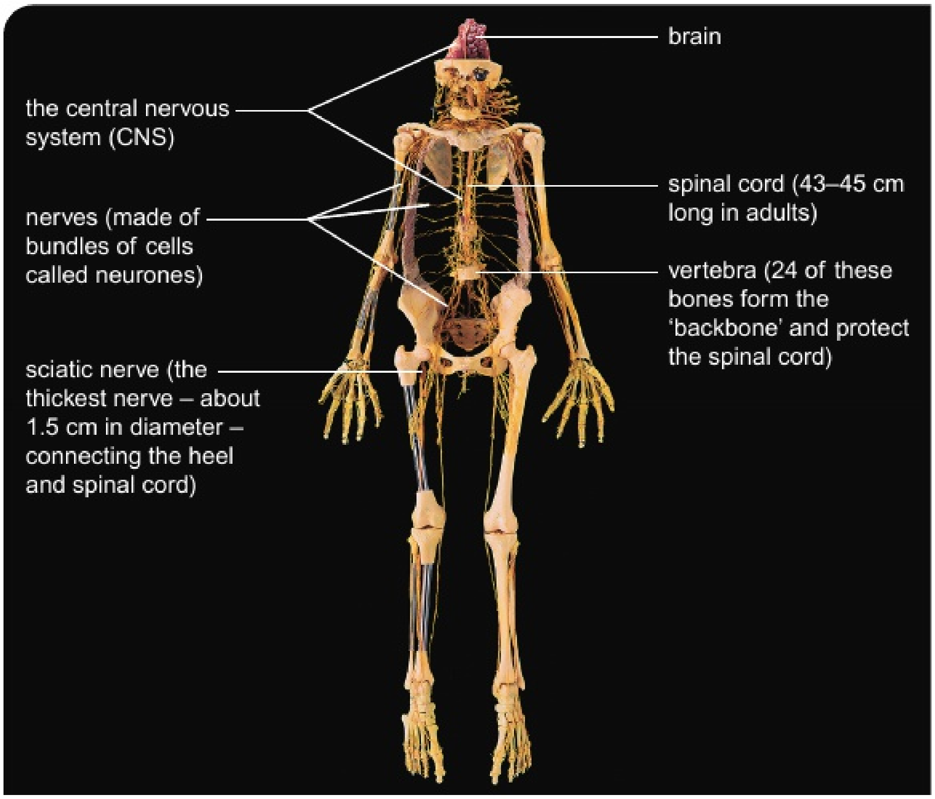
1 Name the organs in the central nervous system.

Did you know?

Lined up end to end, all the neurones in your body would stretch for 1000 km. You would not, however, see this line, because it would be only 10 μm wide.

To study how a human brain works, it is useful for scientists to experiment on living brain tissue. This cannot be done with living people, but in 2015 scientists from Stanford University in the USA managed to grow brain tissue in their lab by using stem cell techniques.

The brain and **spinal cord** form the **central nervous system** (**CNS**), which controls your body. Nerves make up the rest of the **nervous system**. This organ system allows all the parts of your body to communicate, using electrical signals called **impulses**.


brain
the central nervous system (CNS)
spinal cord (43–45 cm long in adults)
nerves (made of bundles of cells called neurones)
vertebra (24 of these bones form the 'backbone' and protect the spinal cord)
sciatic nerve (the thickest nerve – about 1.5 cm in diameter – connecting the heel and spinal cord)

B dissection of the human nervous system, including some of the thicker nerves

Anything your body is sensitive to, including changes inside your body and in your surroundings, is called a **stimulus**. **Sense organs** (such as eyes, ears and skin) contain **receptor cells** that detect stimuli. For example, skin contains receptor cells that detect the stimulus of temperature change.

Receptor cells create impulses, which usually travel to the brain. The brain then processes this information and can send impulses to other parts of the body to cause something to happen (a **response**).

2 In which sense organ would you find receptor cells that detect changes in light?

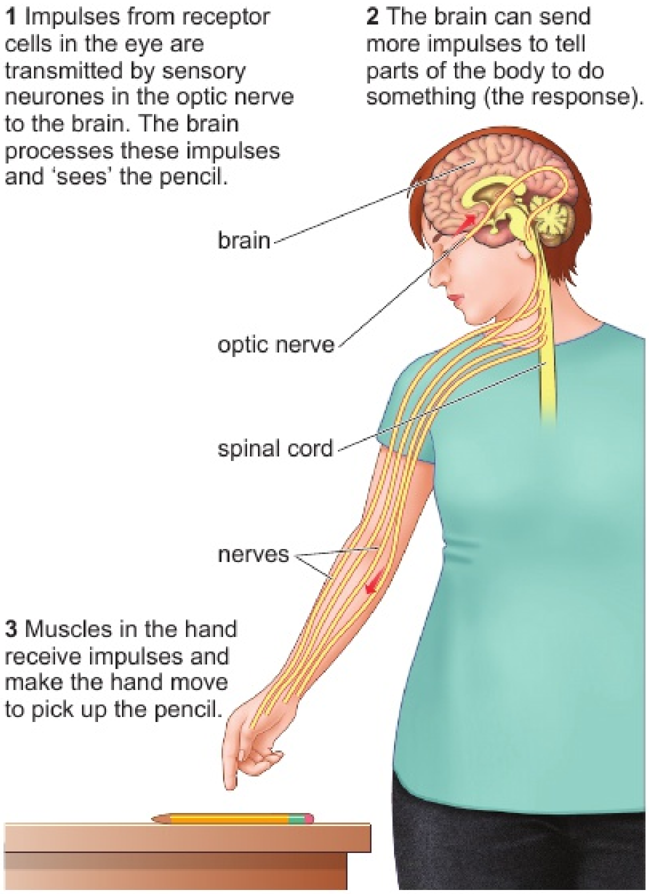
3 How will the person in diagram C know that she has picked up the pencil?

4 You hear a track you like on a playlist and turn up the volume. Describe what happens in your nervous system when you do this.

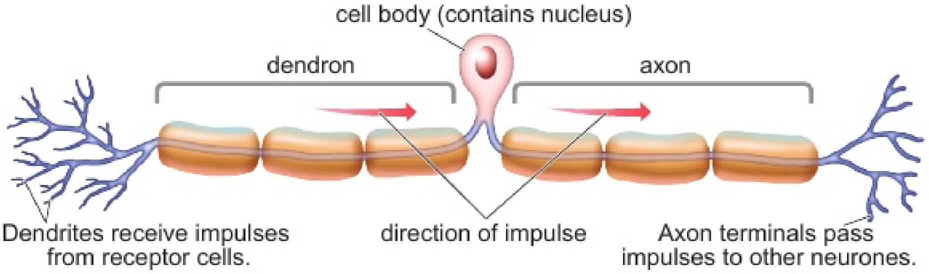
The travelling, or transmission, of impulses is called **neurotransmission** and happens in **neurones** (**nerve cells**). Neurones have a cell body and long extensions to carry impulses.

There are different types of neurone. Diagram D shows a **sensory neurone**. Its function is to carry impulses from receptor cells towards the CNS. A receptor cell impulse passes into a tiny branch called a **dendrite**. It is then transmitted along the **dendron** and the **axon**. A series of **axon terminals** allow impulses to be transmitted to other neurones.

Dendrons and axons are frequently long, to allow fast neurotransmission over long distances. There is also a fatty layer surrounding these parts, called the **myelin sheath**. This electrically insulates a neurone from neighbouring neurones (e.g. in a nerve), stopping the signal losing energy. It also makes an impulse 'jump' along the cell between the gaps in the myelin, and so speeds up neurotransmission.


1 Impulses from receptor cells in the eye are transmitted by sensory neurones in the optic nerve to the brain. The brain processes these impulses and 'sees' the pencil.
2 The brain can send more impulses to tell parts of the body to do something (the response).
brain
optic nerve
spinal cord
nerves
3 Muscles in the hand receive impulses and make the hand move to pick up the pencil.

C This is what happens in the nervous system when someone picks up a pencil.


cell body (contains nucleus)
dendron
axon
Dendrites receive impulses from receptor cells.
direction of impulse
Axon terminals pass impulses to other neurones.

D a sensory neurone

5 **a** Suggest the name of a cell that a dendrite might receive an impulse from.

b Draw a flow chart to show the route of an impulse along a sensory neurone.

6 Explain the ways in which a sensory neurone is adapted to its function.

7 Explain what is meant by a 'response to a stimulus'.

Exam-style question

Describe how you detect the stimulus of temperature change. *(3 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a flow chart to show how information about something touching the heel of your foot gets to your brain.

Extend

E1 You pick up an ice cube. Explain how your nervous system allows you to do this.

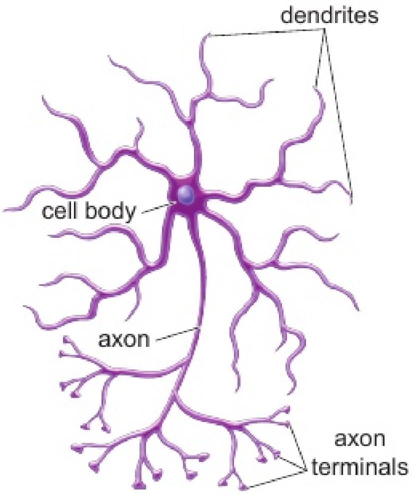
CB2f Neurotransmission speeds

Specification reference: B2.13; B2.14

Progression questions

- How is a motor neurone adapted to its function?
- How do neurotransmitters allow a connection between neurones?
- How does the structure of a reflex arc allow faster reactions to stimuli?

A Lance Corporal Craig Lundberg was blinded by a grenade but gets around unaided using the BrainPort®.



B a relay neurone

2 Do the following carry information to or away from the central nervous system?

a motor neurones

b sensory neurones

The device in photo A allows blind people to see … with their tongues! The image from the camera is sent to a ‘lollipop’ that contains hundreds of small electrodes. Each electrode produces pulses of electricity depending on how much light is in that part of the image. By putting the lollipop on the tongue, the user can feel these pulses and build up an idea of basic shapes and movement. This allows some blind people to react and respond to visual stimuli.

When the brain coordinates a response to a stimulus, impulses are sent to **effectors** and these carry out an action. Effectors include muscles and glands (e.g. sweat glands).

1 Imagine you see a lion and run away.

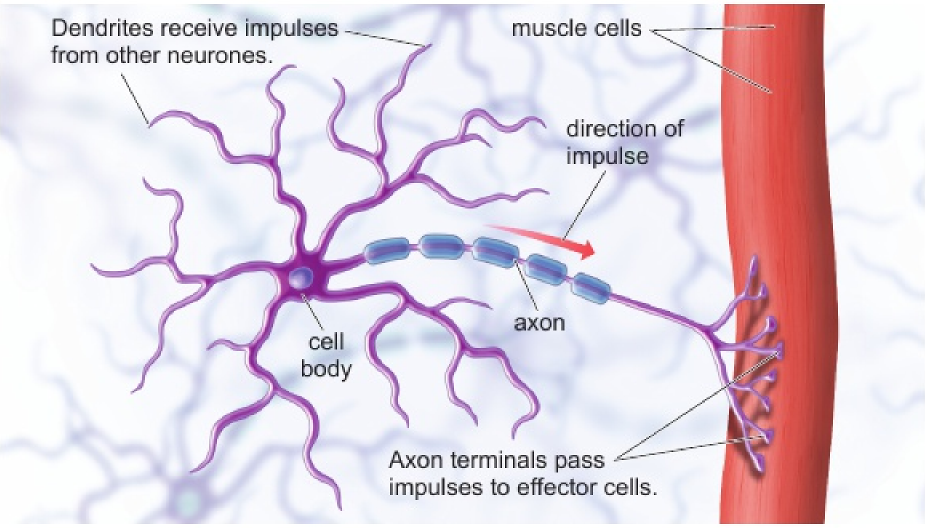
a Where are the receptor cells that receive the stimulus?

b What effectors carry out the response?

c Suggest another effector triggered by seeing the lion.

Different neurones

Motor neurones carry impulses to effectors. **Relay neurones** are short neurones that are found in the spinal cord, where they link motor and sensory neurones. They also make up a lot of the nerve tissue in the brain. Neither of these types of neurone has a dendron, and the dendrites are on the cell body.

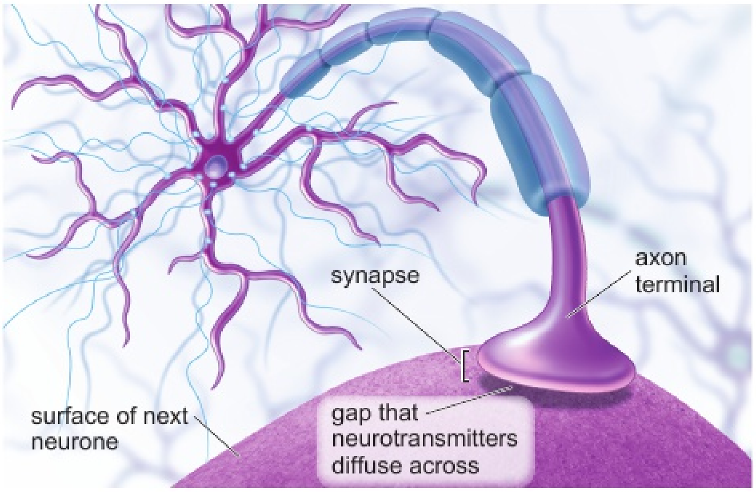

Dendrites receive impulses from other neurones.
muscle cells
direction of impulse
cell body
axon
Axon terminals pass impulses to effector cells.

C a motor neurone

Synapses

One neurone meets another at a **synapse**, which contains a tiny gap. When an impulse reaches an axon terminal, a **neurotransmitter** substance is released into the gap. This is detected by the next neurone, which generates a new impulse. Synapses slow down neurotransmission. They are, however, useful because neurotransmitters are only released from axon terminals and so impulses only flow in one direction. They also allow many fresh impulses to be generated in many neurones connected to one neurone – the original impulse does not need to be split and lose 'strength'.

3 Give two reasons why synapses are used in the nervous system.



D The gap in a synapse is only about 20 nm (0.00002 mm) wide.

4 Reflexes in your eyes cause you to blink if something flies towards you and cause your pupils to shrink in bright light. Why are these responses useful?

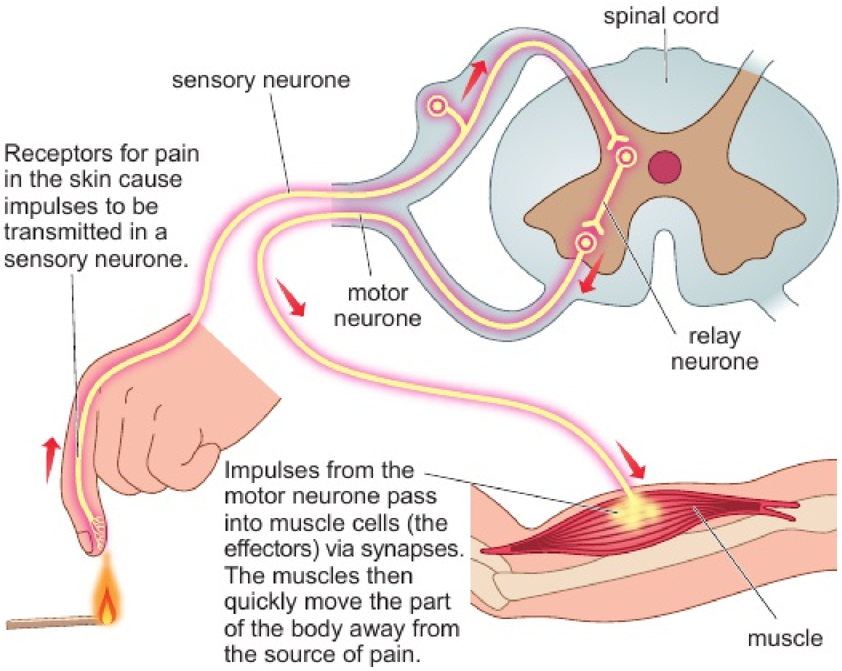
5 Draw a table to compare and contrast reflex actions with processed responses.

6 Suggest why there are very few synapses between the receptor and effector in a reflex arc.

7 You kick a football. Describe how this response occurs.

The reflex arc

If you touch a very hot object you need to pull your finger away very quickly to stop it burning you. You don't want to have to waste time thinking about this and so a **reflex** is used. Reflex actions are responses that are automatic, extremely quick and protect the body. They use neurone pathways called **reflex arcs**, which bypass the parts of the brain involved in processing information and so are quicker than responses that need processing.


spinal cord
sensory neurone
Receptors for pain in the skin cause impulses to be transmitted in a sensory neurone.
motor neurone
relay neurone
Impulses from the motor neurone pass into muscle cells (the effectors) via synapses. The muscles then quickly move the part of the body away from the source of pain.
muscle

E a reflex arc

Exam-style question

Describe how the arrival of an impulse at the end of one neurone can cause an impulse in a neighbouring neurone. *(3 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a flow chart to show how an impulse in a relay neurone causes an impulse in a motor neurone.

Extend

E1 Explain how response times are decreased in reflex actions.

Reflex arc

Describe how impulses are transmitted in a reflex arc in order to reduce the chance of getting burnt when someone touches a hot object. (6 marks)

Student answer

If you touch a hot object, receptor cells in the hand detect this. Impulses travel into a sensory neurone, and then into a relay neurone in the spinal cord. After [1] *this, the impulses pass to motor neurones, which cause muscles (the effectors) to move the hand quickly out of the way* [2]. *This pathway is called a reflex arc, and it is shorter than if the impulses had to go to the brain to be processed. This means that the response is much quicker than usual* [3]. *This means that the hand is moved away from the hot object as quickly as possible, meaning that there is less chance of it being burnt* [4].

[1] The answer shows good use of prepositions such as 'then' and 'after' to show order.

[2] The neurones are described in the correct order.

[3] A good explanation of why the hand moves away so quickly.

[4] The answer relates back to the question, which was about the chance of being burnt.

Verdict

This is a strong answer. The answer is arranged logically and written clearly. It shows good linking of scientific knowledge to the context of the question.

The answer first describes the reflex arc in the correct order, and uses the correct scientific names for the neurones. The answer then links the description to the speed of response, and then to the reduced chance of being burnt. This was the original point of the question.

Exam tip

When you have to write about a sequence of events, it is a good idea to write out bullet points of the facts that you will use, and then number them to show the order in which you will use the points. When you have written your answer, neatly cross out your bullet points.

Paper 1

CB3 Genetics

This image was made by splicing together a photograph of a mother (aged 52) and her son (aged 30). It is one of a number of 'genetic portraits' created by Canadian graphic designer Ulric Collette to illustrate how closely members of the same family resemble one another. In this unit you will learn about the DNA code that produces our features and the processes that allow features to be passed on from parents to their offspring.

The learning journey

Previously you will have learnt at KS3:

- about the differences between environmental and inherited (or genetic) variation
- how two gametes fuse during fertilisation to produce a single zygote
- how the nuclei of eukaryotic cells contain chromosomes, which contain DNA.

In this unit you will learn:

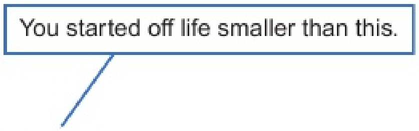
- how gametes are produced by meiosis
- about the structure of DNA
- about mutations and how genes cause genetic variation
- why certain characteristics are passed down through families.

CB3a Meiosis

Specification reference: B3.3; B3.5

Progression questions

- What happens in meiosis?
- Why is meiosis necessary for sexual reproduction?
- What is the role of the genome in the manufacture of proteins?


You started off life smaller than this.

A A human zygote is 0.1 mm in diameter, which is even smaller than this tiny dot.

Did you know?

There are about 37 million million cells in an adult human.

5th **1** State the names of the human gametes.

6th **2** Name the process that turns the zygote into a ball of cells.

3 How many individual chromosomes do the following cells have?

6th **a** human sperm cell

6th **b** human liver cell

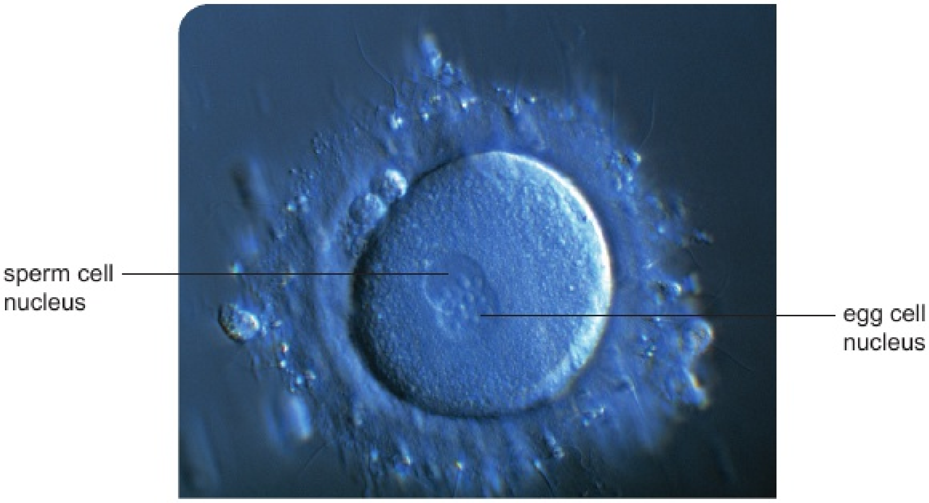
7th **c** human zygote

6th **4** How much of an organism's genome does a gamete contain?

6th **5** Define the term 'gene'.

Humans start life as a single fertilised egg cell, a **zygote**. This is formed when two **gametes** (sex cells) fuse during **fertilisation**. The zygote then forms a ball of cells using a type of cell division called **mitosis** (see CB2a).

Almost all human cells carry exactly the same instructions. These instructions control each individual cell, and also shape, coordinate and control our bodies. So, it's amazing that all the instructions fit into the nucleus of the zygote (the nucleus is about 6 μm or 0.006 mm in diameter).



B a human **sperm cell** nucleus and an **egg cell** nucleus fusing during fertilisation

The instructions for an organism are found as code in a molecule called **DNA**. The DNA of an organism is its **genome**, and most cells contain a complete copy of an organism's genome.

The human genome is found on 46 very long molecules of DNA, and each molecule is inside a **chromosome**. Along the length of a DNA molecule are sections that each contain a code for making a protein. These DNA sections are **genes**. Proteins are **polymers**, made by linking different amino acids together in a chain. The order of amino acids is controlled by a gene. Humans have about 20 000 genes.

There are 23 different chromosomes in humans and most nuclei contain two of each type. So, a human body cell contains two sets of 23 chromosomes, making 46 in all. A cell like this is **diploid** (from the Greek for 'double'). The shorthand for this is 2n. If two diploid cells joined in fertilisation, the **zygote** would have four sets of chromosomes, so gametes need to have just one set of chromosomes. They have to be **haploid**. The shorthand for a haploid cell is 1n.

Gamete production

Mitosis produces diploid cells, and so a different process is used to produce gametes – **meiosis**.

Each chromosome **replicates** – makes a copy of itself. The two copies remain attached, making each chromosome look like an X. The two sets of chromosomes 'pair up', forming 23 pairs, and the pairs then separate into two new cells. Next, the two copies of a chromosome in each X-shape split into two more new cells. Meiosis therefore produces four haploid **daughter cells**, which is how gametes are produced.

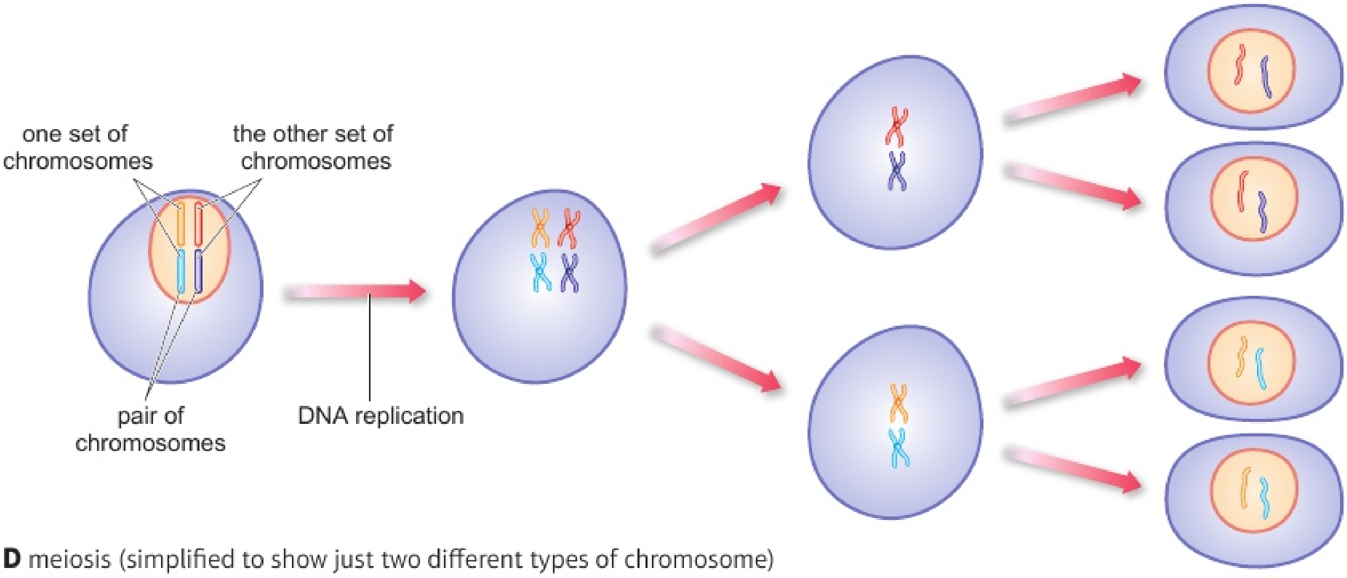
Each chromosome in a pair contains different versions of the same genes. They are 'genetically different'. So, gametes are all different because they contain genetically different chromosomes. This explains why brothers and sisters often look similar but not identical (unless they are identical twins).

C Brothers and sisters have different selections of chromosomes passed down from their parents and so look different to one another.

The gamete-making cell has two sets of chromosomes. It is diploid (2n).

The chromosomes replicate (and the copies stay stuck to one another).

The cell divides into two and then into two again. Each of the final four daughter cells has a copy of one chromosome from each pair. They are haploid (1n).



D meiosis (simplified to show just two different types of chromosome)

6 Explain why chromosomes look X-shaped at the start of meiosis.

7 Name the process in which the following cells are made.

- **a** zygote
- **b** embryo cell
- **c** sperm cell

8 'Triploid syndrome' is a rare human disease. What do you think the cells of someone with this disease are like?

Exam-style question

Compare and contrast mitosis and meiosis. *(3 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a diagram to explain how a zygote's genome is created.

Extend

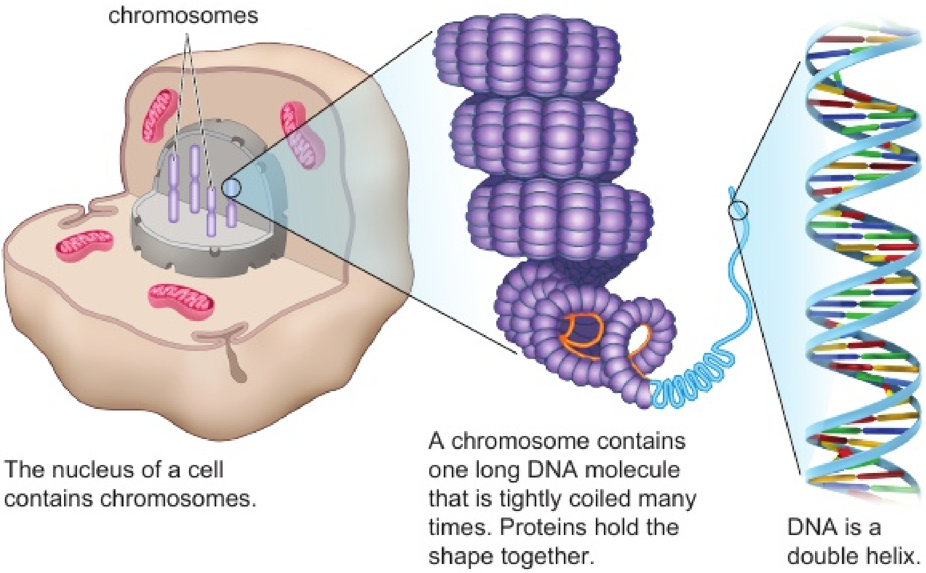
E1 Explain why a brother and sister do not look identical.

CB3bi DNA

Specification reference: B3.4

Progression questions

- What are DNA bases?
- What is the structure of DNA?
- How are DNA strands held together?



The nucleus of a cell contains chromosomes.

A chromosome contains one long DNA molecule that is tightly coiled many times. Proteins hold the shape together.

DNA is a double helix.

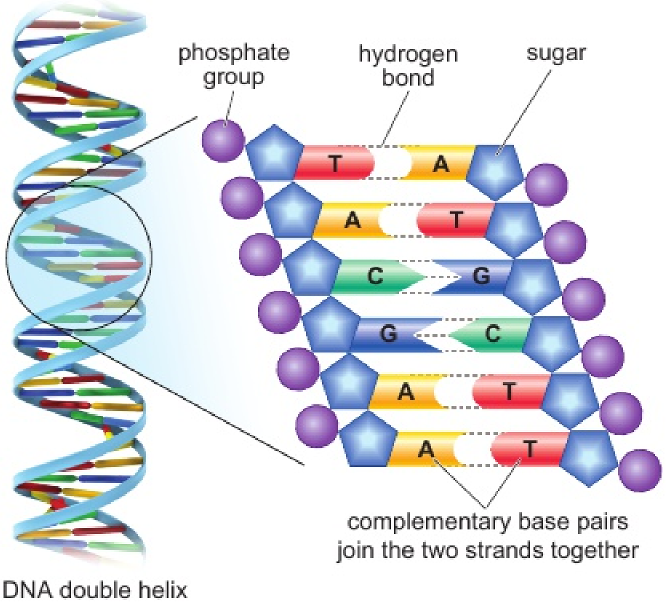
A DNA is packaged up tightly with proteins in a chromosome.

The nuclei of your cells contain very long molecules of **DNA**. Each molecule is tightly coiled and packaged up with proteins to form **chromosomes**.

1 How many molecules of DNA would you expect to find in one of your liver cells?

2 What parts of a DNA molecule contain the instructions for making chromosome packaging proteins?

A molecule of DNA contains two strands, each of which forms a shape called a helix. The two strands are joined together by pairs of substances called **bases**, to form a **double helix**.



B the structure of DNA

There are four bases in DNA: **adenine**, **thymine**, **cytosine** and **guanine**. To make things simpler, we often call them A, T, C and G. Diagram B shows how they are arranged. Notice that A always pairs with T and C always pairs with G. The matching bases are **complementary base pairs**.

Each base is attached to a sugar and each sugar is attached to a phosphate group. The sugars and phosphate groups form the backbone of the DNA strands. DNA is therefore made of many similar units joined in a chain, and so it is a polymer.

3 Describe the shape of a DNA molecule.

4 If cytosine is found on one strand of DNA, which base will it join with on the other strand?

5 One part of a DNA strand contains this order of bases: ATTTCGC. Copy the letters and write the letters for the complementary base pairs underneath.

Hydrogen bonding

Parts of DNA bases have very slight electrical charges. A slightly negatively charged part of one base attracts a slightly positively charged part of another base. This forms a weak force of attraction called a **hydrogen bond**. Cytosine and guanine form three hydrogen bonds between them. Adenine and thymine form two hydrogen bonds. This helps to explain why C only pairs with G, and A pairs with T.

The DNA code

The order of bases in a **gene** contains the coded instructions for a protein. However, we all have slight differences in our genes caused by slightly different orders of bases in our DNA. In fact, everyone except identical twins has different DNA. This allows scientists to match DNA from cells to specific people. And, since DNA is passed down through families, analysing DNA allows scientists to find out if or how people are related.

C the skeleton of Richard III

DNA analysis helped to solve the identity of a skeleton found under a car park in Leicester in 2012. The skeleton looked like it was that of King Richard III, who died in 1485. DNA tests on the bones and on cells from a living relative of the king supported this idea.

D a model of Richard III with one of his living relatives, Michael Ibsen

Exam-style question

Describe the nature of the genetic code found in a gene. *(2 marks)*

Did you know?

The human genome contains about 3 billion base pairs.

7th **6** Describe a hydrogen bond.

7th **7** What makes genes slightly different from person to person?

8th **8** If you are arrested by the police in the UK, a sample of your cells can be taken. Explain why this is done.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe how complementary base pairs help to form the structure of DNA.

Extend

E1 In some types of DNA analysis, the two strands of a small length of DNA are pulled apart to allow copies of the DNA to be made. Draw a labelled diagram to explain how this process works.

CB3bii DNA extraction

Specification reference: B3.6

Aim

Explain how DNA can be extracted from fruit.

Product Recall

Product Code 50561

Model No. Today's Special Beef Lasagne / Today's Special Spaghetti Bolognese

Barcode Today's Special Beef Lasagne – 25260106 / Today's Special Spaghetti Bolognese – 25260113

Date Code All date codes

What's happened?

Detection of Horse Meat.

Beef Lasagne
Spaghetti Bolognese

A Some meat products were withdrawn from sale when it was discovered they had been mislabelled.

At the beginning of 2013, food scientists in Ireland and the UK found that some brands of beefburger contained horsemeat. Horsemeat is safe to eat, but it is illegal to label foods with the wrong ingredients. More tests were carried out on meat products in many countries, and it soon became clear that horsemeat was being used in a variety of 'beef' products throughout Europe. Eventually, people were identified who had mislabelled horsemeat as beef and they were arrested.

During testing, DNA was first extracted from cells in the foods. The DNA was then analysed to work out the order of some of the bases. Different organisms have different orders of bases in certain genes, and so these tests can identify which organisms have been used to make a food. One method of extracting DNA is given below.

Method

Wear eye protection.

A Dissolve 3 g of salt in 100 cm^3 of water in a large beaker. Add 10 cm^3 of washing-up liquid and stir gently until the salt dissolves. Do not make the mixture foamy! The detergent in this solution breaks down cell surface membranes and the membranes around nuclei. The salt makes the DNA more likely to clump together, which is important in step G.

B Thoroughly mash 50 g of peas. Put the mashed peas into an empty beaker and add the solution made in step A. Stir slowly for one minute.

C Place the beaker in a water bath at 60 °C for 15 minutes.

D Filter the mixture and collect the filtrate in a small beaker.

E Measure 10 cm^3 of the filtrate and pour it into a boiling tube.

F Add two drops of protease enzyme solution. (Proteases break down proteins.)

G Tilt the boiling tube slightly and pour in ice-cold ethanol, letting the ethanol run down the inside of the tube very slowly. Stop when as much ethanol has been added as there is filtrate. DNA is insoluble in ethanol and so it forms a precipitate.

H Leave the tube for a few minutes. A white layer forms between the filtrate and the ethanol. This is DNA, and it can be wound around a glass stirring rod and lifted out of the tube.

B Ethanol causes DNA to precipitate, so you can see it.

Exam-style questions

1 **a** State the reason why food scientists analyse the DNA from meat products. *(1 mark)*

b Suggest an explanation for why DNA is so useful for this purpose. *(2 marks)*

2 State which substance is used to precipitate DNA? *(1 mark)*

3 Most of the 'meat' in a food is made of muscle proteins called actin and myosin. State where the instructions for making these proteins are found in an animal. *(1 mark)*

4 Make a list of the apparatus needed to carry out the method on the previous page. *(2 marks)*

5 Draw a labelled diagram to show the apparatus used in step D. *(2 marks)*

6 Explain two safety precautions that should be used when carrying out the experiment on the previous page. *(4 marks)*

7 Explain how the following steps in the method on the previous page allow a good sample of DNA to be extracted in:

a step B *(2 marks)*

b step F. *(2 marks)*

8 The pea DNA produced in step H of the method was put into a new test tube. Twice the volume of ammonia solution as the DNA sample was added, followed by a few drops of silver nitrate. The solution turned cloudy white, indicating the presence of adenine and/or guanine. Explain why this test should be done on the sample of DNA. *(2 marks)*

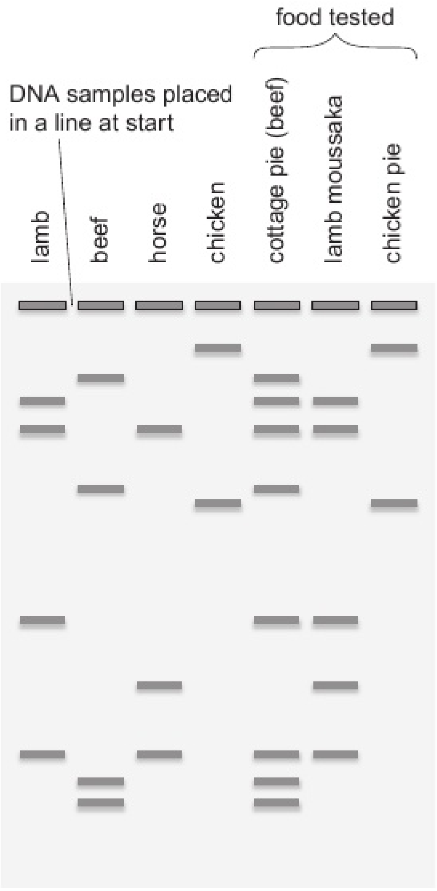
9 DNA is often analysed by chopping it up into small pieces. Where the cuts occur in the DNA is due to the order of the bases. The sizes of the pieces produced are different for different organisms. A form of chromatography is then used to separate the pieces of DNA, with smaller pieces travelling further than larger pieces. The results can then be examined. Diagram C shows the results of one of these tests on the meat in three pre-packed foods.

a State what substance would be added to the DNA samples to chop them into smaller pieces. *(1 mark)*

b Explain which meat produced the smallest size pieces of DNA. *(2 marks)*

c Explain which food(s) contain(s) only the meat they should. *(2 marks)*

d Identify the meats in the illegal food(s). *(2 marks)*



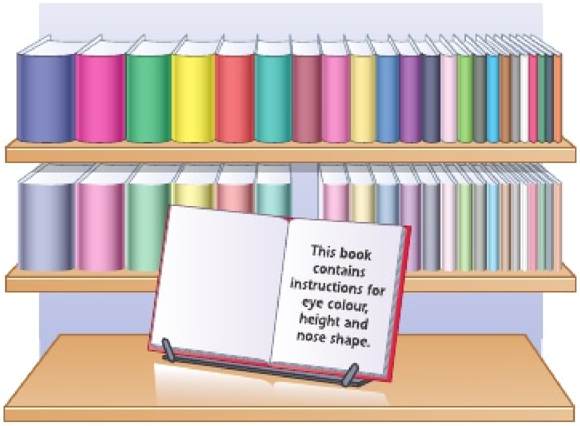
C

CB3c Alleles

Specification reference: B3.12; B3.13; B3.14

Progression questions

- What is the difference between a gene and an allele?
- Why will a recessive allele not affect the phenotype of an organism that is heterozygous for that gene?
- Why are genetic diagrams useful?


This book contains instructions for eye colour, height and nose shape.

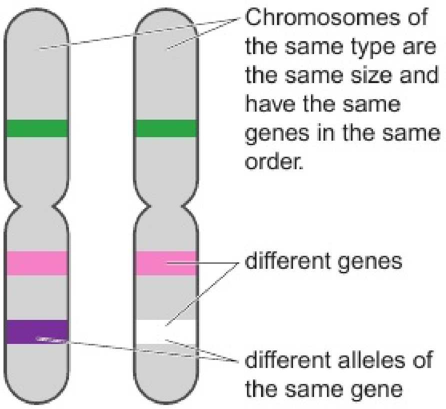
A The human genome is contained on two sets of 23 chromosomes.

You can think of chromosomes as a set of books. Each book (chromosome) contains a set of sentences giving instructions (genes). All of the books together contain all of the instructions needed to produce a certain organism (its genome).

1 List these terms in order of size, largest first: base, chromosome, gene, genome.

Genes for the same characteristic (e.g. eye colour) can contain slightly different instructions that create variations (e.g. brown, blue). Different forms of the same gene are called **alleles**.

Since there are two copies of every chromosome in a body cell nucleus, a body cell contains two copies of every gene. Each copy of a gene may be a different allele. There are many alleles for most of the 20 000 human genes, and the different combination of alleles in each person gives each of us slightly different characteristics (**genetic variation**).


Chromosomes of the same type are the same size and have the same genes in the same order.
different genes
different alleles of the same gene

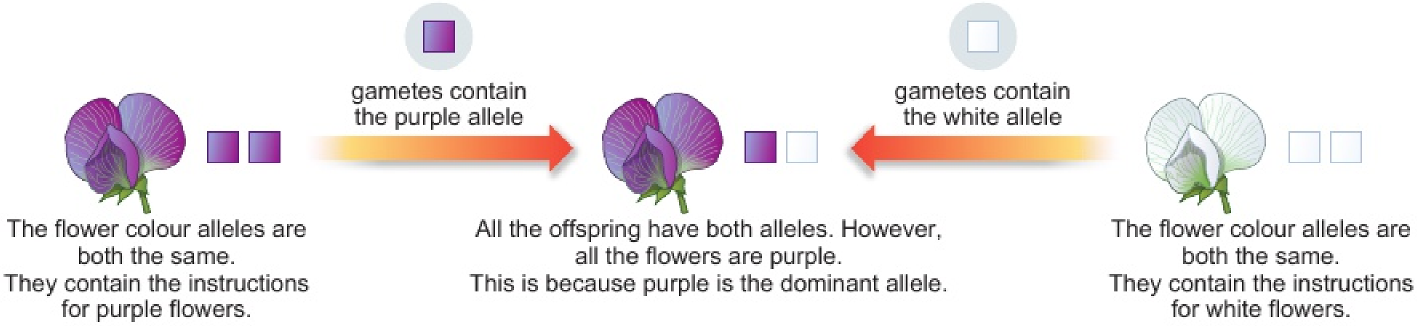
B Each gene can exist in a number of different forms called alleles.

2 Define the term 'allele'.

3 How does the idea of alleles help to explain why we all look different?

If both alleles for one gene are the same, an organism is **homozygous** for that gene. If the alleles are different, an organism is **heterozygous**. The plants on the far left and far right of diagram C are homozygous.

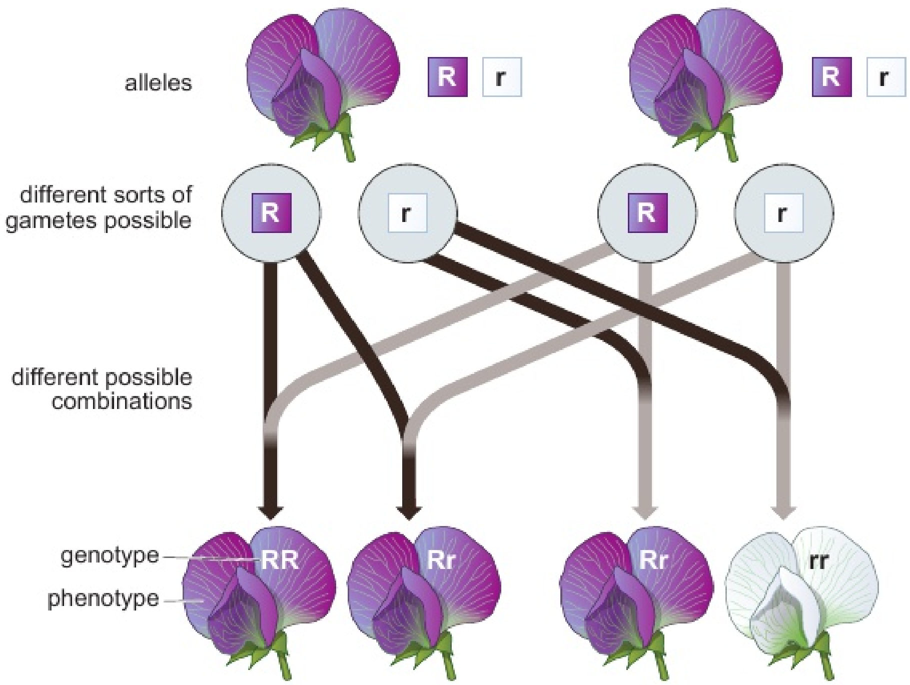
Gametes have only one copy of each chromosome and so only contain one copy of each gene. In diagram C, gametes from the purple and white flowers fertilise and form a **zygote** that is heterozygous. However, in the offspring plant only the allele for purple flowers has an effect. It is said to be **dominant**. The white flower allele has no effect if the purple flower allele is there. This white flower allele is **recessive**.


gametes contain the purple allele
gametes contain the white allele
The flower colour alleles are both the same. They contain the instructions for purple flowers.
All the offspring have both alleles. However, all the flowers are purple. This is because purple is the dominant allele.
The flower colour alleles are both the same. They contain the instructions for white flowers.

C

A recessive characteristic is only seen if *both* alleles are recessive. This can be shown in a **genetic diagram** (diagram D).

A dominant allele is shown by a capital letter (e.g. R for purple). The recessive allele has the lower case version of the *same* letter (e.g. r for *not* purple). The letter for the dominant allele is always written before the recessive one (e.g. Rr and never rR). The alleles in an organism are its **genotype**. What the organism looks like is its **phenotype**.


alleles
R
r
R
r
different sorts of gametes possible
R
r
R
r
different possible combinations
genotype
phenotype
RR
Rr
Rr
rr

D A genetic diagram shows the possible combinations of alleles when two organisms breed. We use diagrams like this to explain the inheritance of one gene (**monohybrid inheritance**). We can also use these diagrams to predict the **ratios** of the phenotypes (purple and white phenotypes are in a 3:1 ratio in this example).

6 When will a recessive allele affect a phenotype?

7 Draw a table to show the three genotypes in diagram D and their matching phenotypes.

8 The pea plant gene for height has two alleles: T (dominant, causing tall plants) and t (recessive, causing short plants). A homozygous tall plant is crossed (bred) with a homozygous short plant. Draw a genetic diagram to show the pattern of monohybrid inheritance of the height gene.

Exam-style question

ADWH is a condition in which people have curly hair that looks like sheep's wool. It is caused by a dominant allele (D). Calculate the ratio of children with and without the condition if one parent is heterozygous and the other is homozygous for the recessive allele. *(4 marks)*

4 How would you add to the book analogy (in diagram A) to include alleles?

5 a Is the plant in the centre of diagram C heterozygous or homozygous for the flower colour allele?

b Explain your reasoning.

Did you know?

The ability to taste a bitter substance called PTC (phenylthiocarbamide) is controlled by one gene. People with a dominant allele of the gene can taste PTC. People with two recessive alleles cannot taste it.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Two pea plants are bred together. One has two dominant alleles for purple flowers (R) and one has two recessive alleles for white flowers (r). Draw a diagram to explain why none of the offspring will have white flowers.

Extend

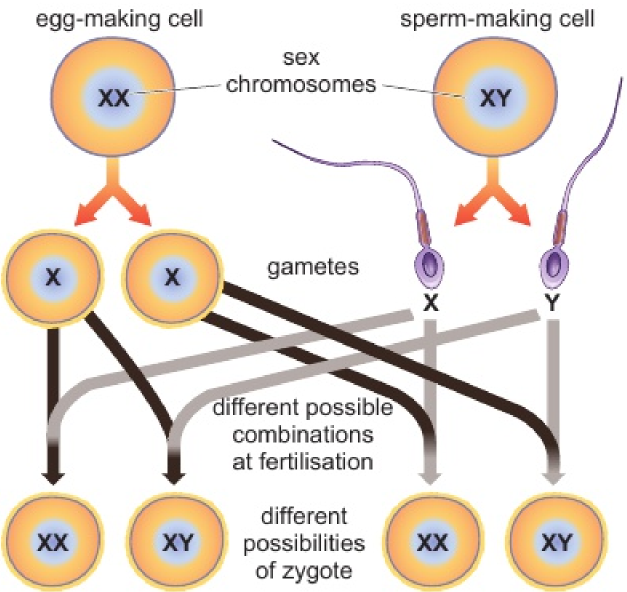
E1 The pea plant gene for seed shape has two alleles: N (causing smooth peas) and n (causing wrinkled peas). Use a genetic diagram to work out the ratio of offspring with smooth and wrinkled peas if the parent plants are both heterozygous.

CB3d Inheritance

Specification reference: B3.14; B3.15; B3.16

Progression questions

- How is the sex of offspring determined in humans?
- How do we use genetic diagrams, Punnett squares and family pedigrees to show inheritance?
- How are the probable outcomes of offspring phenotypes calculated, using information about alleles?


egg-making cell
sperm-making cell
sex chromosomes
XX
XY
X
X
gametes
X
Y
different possible combinations at fertilisation
XX
XY
different possibilities of zygote
XX
XY

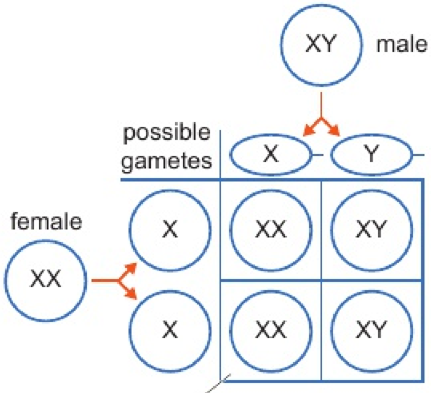
A genetic diagram for sex determination in humans

Two of your chromosomes determine what sex you are. They are your **sex chromosomes** and there are two types: X and Y. Females have two X sex chromosomes and males have one X and one Y.

A woman's gametes (egg cells) all contain an X sex chromosome but male sperm cells contain either an X or a Y. Diagram A shows the ways in which sex chromosomes can combine.

1 In humans, which gamete is responsible for determining the sex of the offspring?

Punnett squares (such as diagram B) are another way to demonstrate inheritance. The boxes show the possible genotypes. Two boxes contain XX and two contain XY, so the ratio of the outcomes is 2:2 (simplified to 1:1). This means that there should be equal numbers of offspring born with XX sex chromosomes as are born with XY.



The boxes show the possible combinations in the offspring.

B Punnett square for human sex determination

The likelihood of an event happening is its **probability**. Punnett squares are used to work out the theoretical probability of offspring inheriting certain genotypes. Probabilities can be shown as fractions, decimals or percentages. The probability of an impossible event is 0 or 0 per cent. The probability of an event that is certain to happen is 1 or 100 per cent.

Worked example

In diagram B, two out of four boxes are XX. So the probability of a child being XX is:

$$\frac{2}{4} = \frac{1}{2} = 0.5$$

Or as a percentage: 50%

Did you know?

Birds have Z and W sex chromosomes and it is the egg cell that determines the sex; the females are ZW and males are ZZ.

2 Explain why about half the population of the UK is female.

Punnett squares are used to work out the probabilities of different phenotypes caused by alleles. Diagram C shows an example for a genetic disorder called cystic fibrosis (CF), caused by a recessive allele. People with CF have problems with their lungs and digestive systems.

People who inherit two recessive CF alleles (f) have the disorder. People who inherit at least one dominant allele (F) do not have CF. The Punnett square shows that if heterozygous parents have children, the ratio of children without CF to those with CF is predicted to be 3:1.

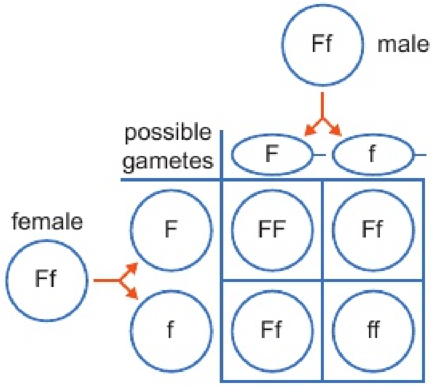
3 Draw a Punnett square for the plants shown in CB3c diagram D.

4 Look at diagram C.

a What is the ratio of the phenotypes of the offspring?

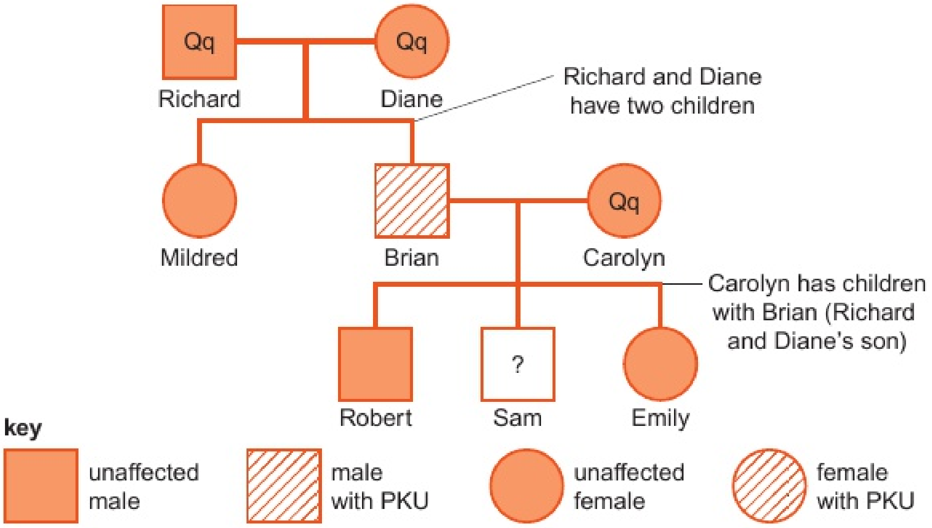
b If the parents had four children, how many are predicted to have CF?

c Calculate the probability of a child being born without CF. Show your answer as a fraction, a decimal and as a percentage, and show all your working.



C Punnett square for parents that are heterozygous for the CF gene

A **family pedigree chart** (such as diagram D, below) shows how genotypes and their resulting phenotypes are inherited in families.



D Phenylketonuria (PKU) is a disorder caused by a recessive allele. People with PKU lack an enzyme called phenylalanine hydroxylase and can develop nerve problems unless they stick to a special diet.

5 Look at diagram D.

a Which letter shows the recessive allele?

b Why doesn't Carolyn have PKU?

c What is Brian's genotype?

d Calculate the probability that Sam has PKU. Show your working.

Exam-style question

Explain how the sperm cell is responsible for the determination of sex in humans. *(4 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Look at diagram D. Draw a Punnett square for Richard and Diane.

S2 Work out the probability that a child of theirs will have PKU. Show all of your working.

Extend

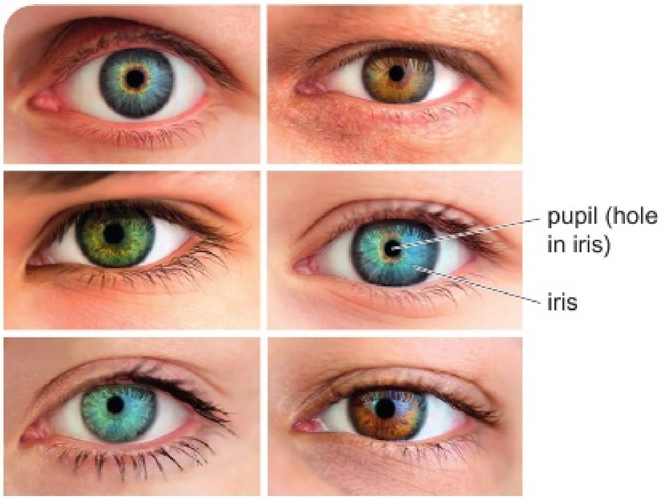
E1 The pea plant gene for unripe pod colour has two alleles: G (green pods) and g (yellow pods). Two homozygous plants are crossed (bred together), one with green pods and one with yellow pods. Two of the offspring are crossed. Work out the probability that an offspring plant from this second crossing will have yellow pods. Show all of your working.

CB3e Gene mutation

Specification reference: B3.19; B3.20; B3.21; B3.22; B3.23

Progression questions

- Why is it difficult to identify how most inherited characteristics are controlled?
- What is a mutation?
- How can mutations cause variation?



A Human eye colour is caused by the amount of melanin (a dark-coloured protein) and how light is scattered by the iris.

Most human characteristics are controlled by many genes, not just one. For example, several genes affect eye colour in humans. However, most **variation** in eye colour is caused by the OCA2 gene, which controls the amount of melanin produced. Melanin is a protein that makes hair, eyes and skin darker in colour. A blue iris contains little melanin, while a brown iris contains a lot of melanin.

7th **1** Suggest two alleles for the OCA2 gene, and explain your answer.

9th **2** It is sometimes said that brown eyes are dominant to blue eyes. Use this information, and your answer to question 1, to draw a Punnett square that describes the inheritance of eye colour from heterozygous brown-eyed parents. Describe the outcomes in terms of genotype and phenotype.

Did you know?

A baby has about 70 mutations that neither of its parents have. These mutations occur during gamete production and during growth.

It is thought that early humans had brown eyes. As our ancestors moved north from Africa, changes in the alleles for melanin production in some people resulted in blue eyes and fair skin. A change in a gene that creates a new allele is called a **mutation**. Mutations often occur during cell division.

Mutations happen when there is a mistake in copying DNA during cell division. For example, one base in a DNA sequence might be replaced with another, rather like typing the wrong letter in a word. This can happen naturally, but is more likely to happen if there is damage to the DNA caused by radiation or certain substances.

Sometimes a mutation produces an allele that causes a big change in the protein that is produced. This will affect how the body works. However, mutations can occur in different parts of a gene and so may only have a small effect on the protein that is produced. Many other mutations will not change the protein at all and so have no effect on the phenotype.

3 Which kind of cell division could produce a mutation in:

7th **a** a gamete

7th **b** a body cell?

B Sunlight contains ultraviolet radiation that can cause mutations in skin cells, which can result in skin cancer.

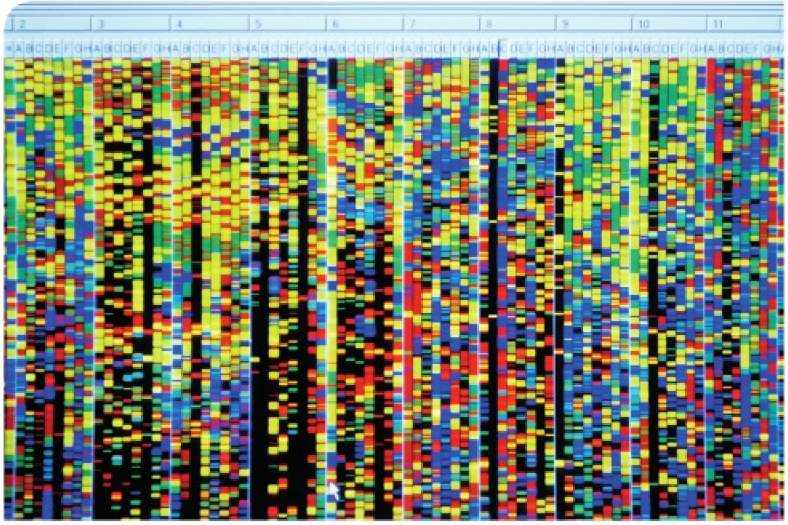
8th **4** Explain why the risk of developing skin cancer can increase with the amount of sunlight your skin receives.

8th **5** Explain why a mutation does not always produce a change in a characteristic.

The Human Genome Project

In 2003, the first complete human genome was decoded. This was the result of the **Human Genome Project** and involved scientists in many different countries. The project produced a map of 3.3 billion complementary base pairs in one set of 46 human chromosomes. Further work has found many sections of DNA that are the genes. Now other human genomes have also been mapped. This has shown that there are variations between people, but that over 99 per cent of the DNA bases in different people are the same.

Mapping a person's genome can indicate their risk of developing diseases that are caused by different alleles of genes. It can also help identify which medicines might be best to treat a person's illness, because the alleles we have can affect how medicines work in the body.



C A map of part of one human genome. Each coloured band represents a different base in the DNA sequence. Some of the bases in this part of the genome will be different in different people.

8th **6** Look at photo C. Explain why some colour bands would be different in this part of the genome from another person.

Clopidogrel is a drug used to prevent blood clots in people at risk of heart attack or stroke. Some people have particular alleles that mean the drug does not protect them.

Drug response	Status
Clopidogrel effectiveness	reduced
Simvastatin-induced myopathy	typical risk
Warfarin sensitivity	increased

The drug simvastatin is used to reduce high levels of cholesterol in the blood. Some people suffer a side effect of myopathy (weak muscles) if they take the drug.

Warfarin is given to people to reduce the risk of blood clots. Some people are more sensitive to the drug than others, due to their alleles, and so need to take a smaller dose than others, otherwise it can cause dangerous bleeding.

D Genome analysis for one person showing how they might respond to some drugs as a result of the alleles they have for particular genes.

6th **7** Give two ways in which information about a person's genome could be useful in medicine.

9th **8** **a** Suggest how a doctor might use the information in table D to identify which drugs to use with that particular person.

8th **b** Explain why the information in table D can be different for different people.

Exam-style question

Explain how mutation can lead to variation in the phenotype. *(3 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Different people have different eye colours. Explain why there is variation in human eye colour.

Extend

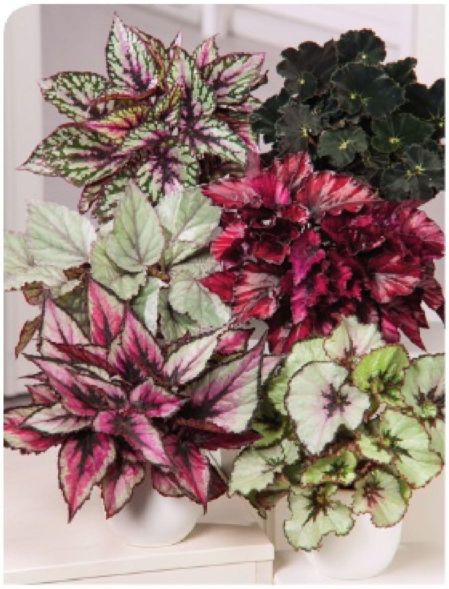
E1 The RHO gene controls the production of a protein in the retina of the eye that helps with vision in low light. The gene is 6705 bases long, and over 150 different variations in some of the bases have been found. Some variations have no obvious effect, but some lead to night blindness by the age of 40. Explain this variation in vision in different people.

CB3f Variation

Specification reference: B3.20

Progression questions

- How is genetic variation caused?
- How can the environment affect characteristics?
- What are discontinuous and continuous variation?



A These plants are all the same species, *Begonia rex*. X-ray radiation was used to produce mutations that led to many new varieties of the species with different shapes and colours of leaves.

Some of the variation between individuals of the same species is the result of variation in their genes. **Genetic variation** is caused by the different alleles inherited during sexual reproduction. Different alleles are produced by mutations, some of which cause changes in the phenotype. However, many characteristics also show **environmental variation**, because they are affected by their surroundings. For example, how well a plant grows is affected by how much light, water and nutrients it gets.

4th **1 a i** Look at photo A. Identify one characteristic in *Begonia rex* plants that is caused by genetic variation.

6th **ii** Explain your answer.

5th **b i** Suggest one characteristic in these plants that shows variation caused by the environment.

6th **ii** Explain your answer.

In a few cases, a characteristic shows variation that is caused only by the environment, such as the loss of a limb in an accident. Characteristics that are changed by the environment during the life of the individual are called **acquired characteristics**.

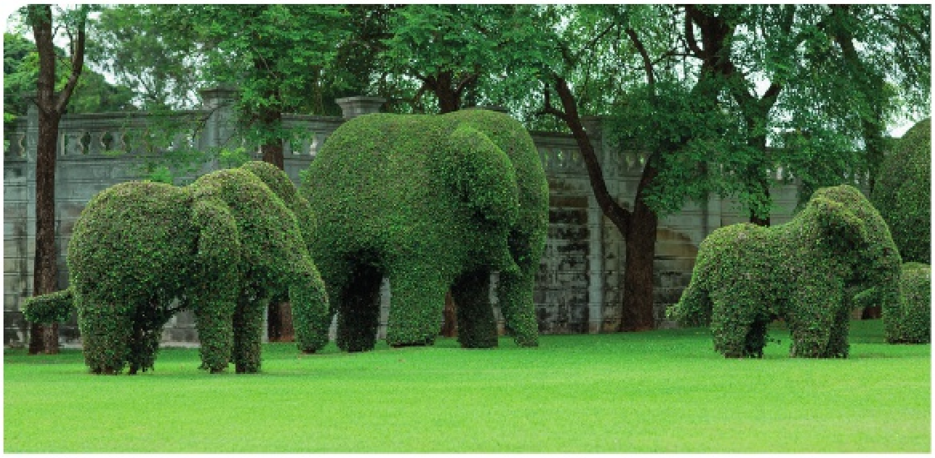
2 For each of these human characteristics, state whether they are controlled only by genes, only by the environment, or by both genes and environment. Explain each of your answers.

5th **a** length of hair

5th **b** blood group

5th **c** height

6th **3** Explain why the shapes of the bushes in photo B are acquired characteristics.



B These bushes have acquired different shapes due to pruning by the gardener.

Variation can be grouped into two types:

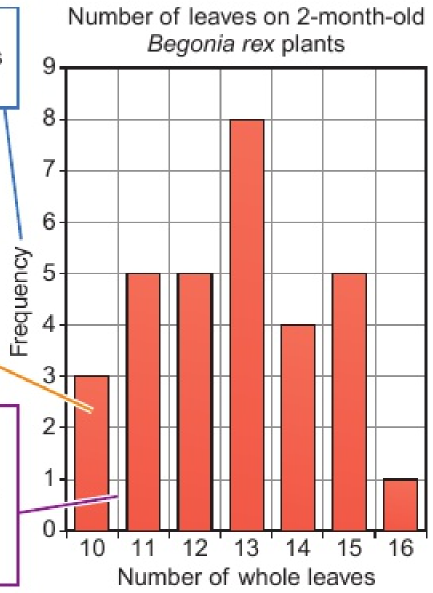
- **discontinuous variation** is where the data can only take a limited set of values
- **continuous variation** is where the data can be any value in a range.

Charts C and D show how to display these different types of variation.

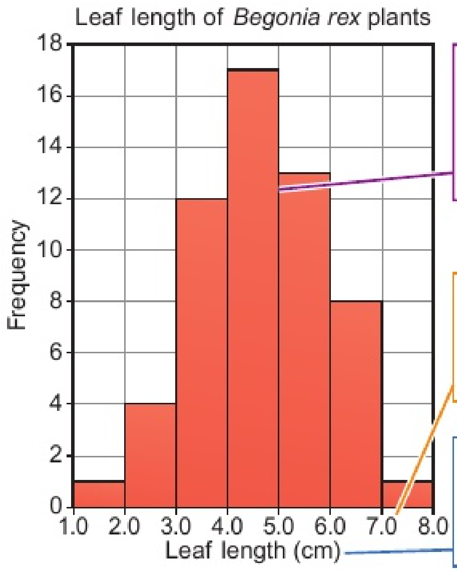
The number of times something occurs is its frequency.

Variation in number of whole leaves is discontinuous because you can only have whole numbers, not values in between.

When drawing a frequency bar chart for discontinuous variation, leave a gap between bars to make the discontinuity obvious.



C This bar chart shows variation in numbers of leaves on a plant. Since the variable on the *y*-axis is frequency, it is also called a frequency diagram.



The chart is drawn with no gaps between bars, to show that the data are continuous.

Values are grouped to make it easier to see patterns in the data.

Leaf length is a continuous variable as it can be any value within the range.

D This bar chart is also a frequency diagram, and shows variation in leaf length from several *Begonia rex* plants.

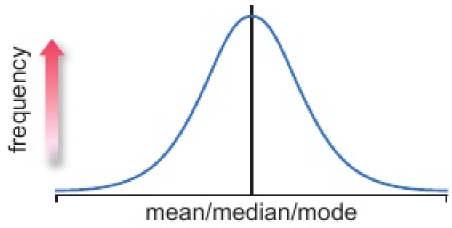
4 Look at charts C and D. Which type of chart would you use for these human characteristics? Explain your answers.

a length of hand

b presence or absence of freckles

Continuous data for variation often forms a bell-shaped curve, known as a **normal distribution** (see graph E). It is called this because it is what is expected for a large amount of data for a characteristic where:

- the most common value is the middle value in the whole **range**
- the further a value is from the median, the fewer individuals have that value.



E In a normal distribution curve, the **mean** value is the same as the **mode** (most common value) and the **median** (the middle value).

5 Look at chart D.

a What is the range of leaf lengths shown in the chart?

b What is the modal class for leaf length shown in the chart?

c Does leaf length in *Begonia* plants show a normal distribution? Explain your answer.

Exam-style question

A group of humans will show variation in height. Describe how this variation is caused. *(2 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 A child has long, wavy blonde hair, but his mother has short, straight brown hair. Give as many reasons as you can for these differences, explaining your answers.

Extend

E1 Is the DNA in each of your cells exactly the same? Explain your answer.

Mitosis and meiosis

Compare the roles of mitosis and meiosis in reproduction. (6 marks)

Student answer

Mitosis is the cell division that produces two diploid daughter cells from one parent cell. During mitosis each daughter cell receives a copy of every chromosome in the parent cell, which means that [1] *they are genetically identical. Mitosis is used in asexual reproduction and produces offspring that are genetically identical to the one parent* [2].

In meiosis, four daughter cells are produced from one parent cell. Each daughter cell is haploid [3], *and has copies of only half the chromosomes of the diploid parent cell. This produces gametes that are genetically different to each other* [4]. *Meiosis occurs before sexual reproduction, in which two gametes fuse to form a fertilised egg cell that is diploid. The variation in the gametes means that the offspring differ genetically from each other and from the two parents* [5].

[1] The student uses a linking phrase ('which means that') to identify cause and effect. This helps to structure the answer and provide links to reasoning.

[2] This part of the answer clearly links mitosis to reproduction – which was one aim of the question.

[3] The answer correctly uses (and correctly spells) scientific terms, such as haploid.

[4] This part of the answer clearly links meiosis to cell division – which was the other aim of the question.

[5] The answer is logically divided into two paragraphs – one about mitosis and one about meiosis. Each of the paragraphs is structured in the same order. This makes the differences between mitosis and meiosis very clear.

Verdict

This is a strong answer. It contains detail about both types of cell division, and uses appropriate scientific terminology.

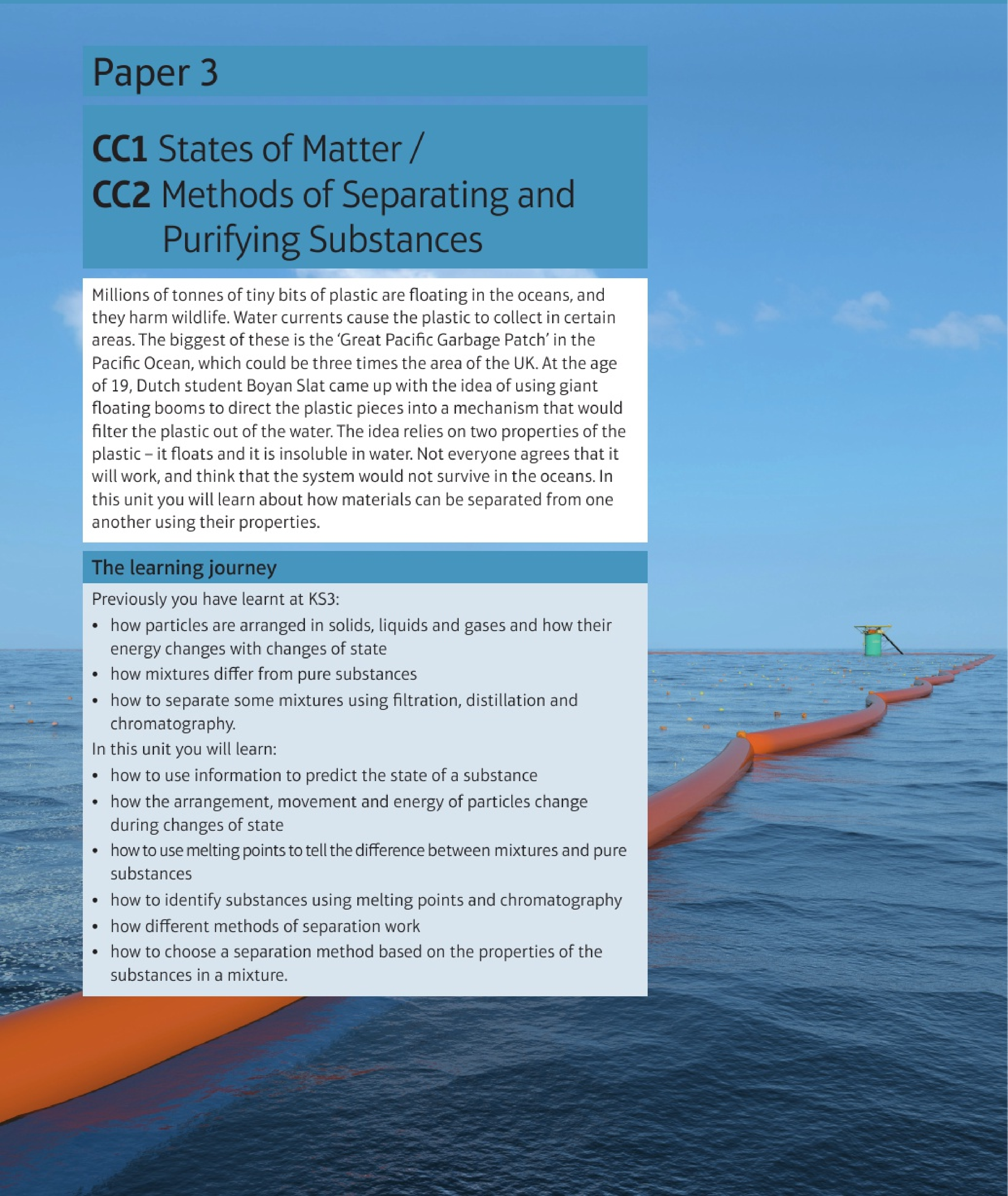
The answer also clearly links the description of each type of cell division with what this means for reproduction. The answer is well organised and makes it easy to compare the differences between each process.

Exam tip

The answer to a 'compare' question should describe the similarities *or* differences between **all** the subjects of the question (in this case the answer includes differences between *both* types of cell division). A 'compare' question does not need a conclusion.

Paper 3

CC1 States of Matter / **CC2** Methods of Separating and Purifying Substances



Millions of tonnes of tiny bits of plastic are floating in the oceans, and they harm wildlife. Water currents cause the plastic to collect in certain areas. The biggest of these is the 'Great Pacific Garbage Patch' in the Pacific Ocean, which could be three times the area of the UK. At the age of 19, Dutch student Boyan Slat came up with the idea of using giant floating booms to direct the plastic pieces into a mechanism that would filter the plastic out of the water. The idea relies on two properties of the plastic – it floats and it is insoluble in water. Not everyone agrees that it will work, and think that the system would not survive in the oceans. In this unit you will learn about how materials can be separated from one another using their properties.

The learning journey

Previously you have learnt at KS3:

- how particles are arranged in solids, liquids and gases and how their energy changes with changes of state
- how mixtures differ from pure substances
- how to separate some mixtures using filtration, distillation and chromatography.

In this unit you will learn:

- how to use information to predict the state of a substance
- how the arrangement, movement and energy of particles change during changes of state
- how to use melting points to tell the difference between mixtures and pure substances
- how to identify substances using melting points and chromatography
- how different methods of separation work
- how to choose a separation method based on the properties of the substances in a mixture.

CC1a States of matter

Specification reference: C2.1; C2.2; C2.3; C2.4

Progression questions

- What are particles like in substances in the solid, liquid and gas states?
- What changes happen to particles during the different changes of state?
- How do you decide what state a substance will be in at a given temperature?

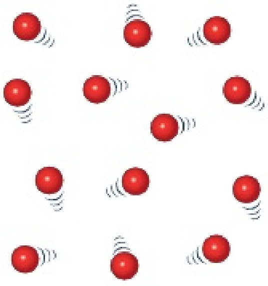
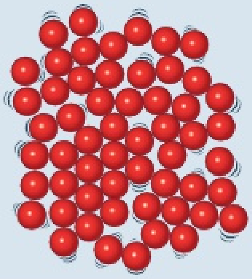
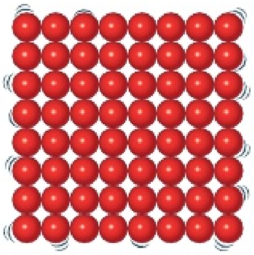
A This 'ice hotel' is made entirely from ice and snow – these are both water in the solid state.

The three **states of matter** are solid, liquid and gas. For example, water can exist in the solid state as ice, or in the familiar liquid state, or in the gas state as steam or water vapour.

The particle model

Some **particles** are large enough to see, like the dust on a computer screen. Others, like **atoms** and **molecules**, are far too small for you to see. When chemists discuss particles, they usually mean these very small particles.

The **particle model** explains state changes in a substance in terms of the arrangement, movement and energy stored in its particles.

State	Particle diagram	Arrangement of particles	Movement of particles
Gas		random far apart	fast in all directions
Liquid		random close together	move around each other
Solid		regular close together	vibrate about fixed positions

B Particles in the solid state contain the smallest amount of stored energy; particles in the gas state contain the most.

Did you know?

Science recognises 16 different types of ice, depending on the arrangement of the water molecules. A type called amorphous ice is found in space (such as on comets). A type called Ice IV is what you'll find in a kitchen freezer, here on Earth.

1 Describe the difference in the arrangements of particles in a solid and in a liquid.

2 Describe the difference in the movement of particles in a liquid and in a gas.

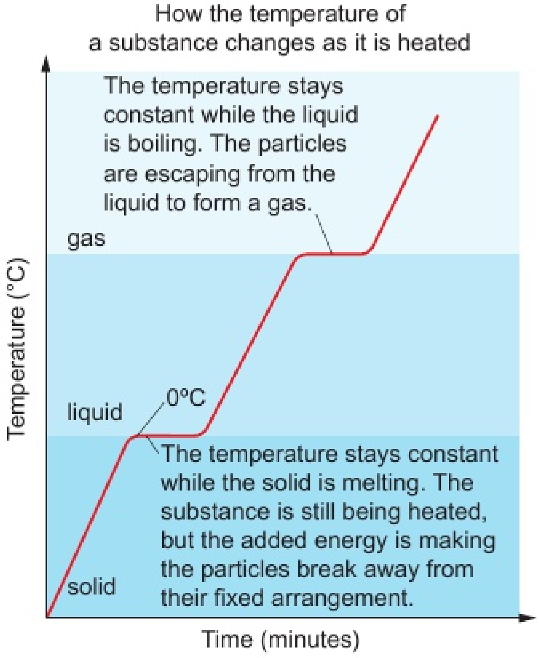
State changes

State changes are **physical changes**. They can be reversed, and the **chemical properties** of the substance do not change. This is because the particles themselves do not change – only their arrangement, movement and amount of stored energy.

3 State the meaning of the terms 'sublimation' and 'deposition'.

Particles are attracted to one another by weak forces of attraction. There are many of these forces in a solid. Some of these are overcome during melting. The remaining **attractive forces** between particles in a liquid are overcome during evaporation and boiling (when a substance is evaporating as fast as it can). For this to happen, energy must be transferred from the surroundings to the particles. This is why you heat ice to melt it, and why you boil water in a kettle. Diagram D shows how the temperature changes when water in the solid state is heated until it reaches the gas state.

Some attractive forces form between particles during condensing, and many attractive forces are formed during freezing. For this to happen, energy must be transferred from the particles to the surroundings. This is why water vapour turns into water droplets on a cold window, and why you put water in a freezer to make ice.



D a heating curve for water

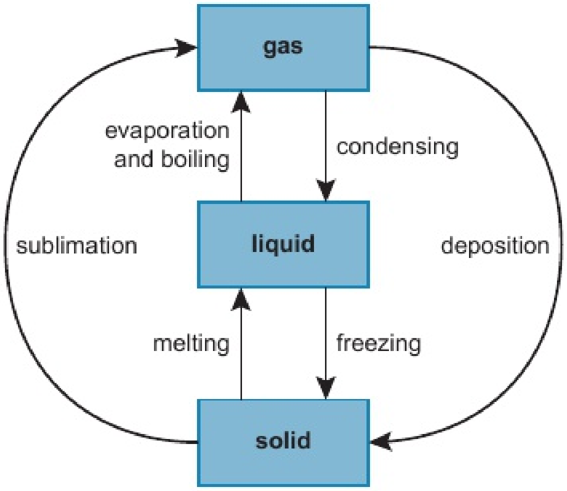
You can predict the state of a substance if you know its temperature, and its **melting point** and **boiling point**. If the temperature is:

- below the melting point, the substance is solid
- between the melting point and boiling point, the substance is liquid
- above the boiling point, the substance is gas.

Exam-style question

Camping gas is used by campers and hikers. It is a mixture of propane and butane. Explain, in terms of the arrangement of fuel particles, why camping gas is stored in cylinders as a liquid rather than as a gas.

(2 marks)



C the interconversions between the three states of matter

4 Describe how you can see from a 'heating curve' (such as diagram D) that a substance is changing state.

5 Explain what happens to the particles when a substance melts.

6 The melting point of gallium is 29.8 °C and its boiling point is 2204 °C. Predict its state at 25 °C, 100 °C and at 2205 °C.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a diagram to show the states of matter. On your diagram, name each state change and describe what happens to the particles as it happens.

Extend

E1 Explain why the arrangement, movement and energy of particles change during changes of state.

CC2a Mixtures

Specification reference: C2.5; C2.6

Progression questions

- What is the difference between a pure substance and a mixture?
- What happens to its particles when a solid melts?
- How do melting points allow you to spot the differences between pure substances and mixtures?

A You can tell this gold bar is very nearly pure because of the '999.9' stamped on it. A number lower than 1000 on this 'fineness' scale means it is impure.

The composition (make-up) of a **pure** substance:

- cannot be changed
- is the same in all parts of a piece of the substance.

So, for example, pure gold contains only gold atoms.

5th **1** Which type of atoms are found in a piece of pure silver?

5th **2** State what is meant be the term 'impure'. Explain what the term 'impure' means.

Gold is an **element** and can be pure, but **compounds** can also be pure. The sugar we use at home is a compound called sucrose. It contains carbon, hydrogen and oxygen atoms chemically bonded together to form sucrose molecules. You cannot change the composition of pure sucrose.

Did you know?

The purest gold ever was produced in 1957 and was 999.999 on the fineness scale.

Gold purity is still often measured on the older carat scale, where 24 carat gold is pure gold.

5th **3** **a** Describe what a mixture of carbon, hydrogen and oxygen might look like.

4th **b** Describe how you would separate marbles from sand.

5th **4** Oxygen can be removed from air by cooling. Explain why this would not be possible if air were not a mixture.

B Pure sucrose is always sucrose, no matter how finely it is ground down.

A pure substance has the same fixed composition in all its parts and so we can't separate it into other substances using physical methods (such as filtering or picking bits out).

A **mixture** contains elements and/or compounds that are not chemically joined together. You *can* use physical processes to separate mixtures into different substances.

A mixture does not have a fixed composition. For example, air is a mixture of gases. When students sit in a classroom, they use up oxygen and breathe out carbon dioxide and so the composition of the air in the room changes. We still call it 'air', but because air is a mixture its composition can change.

Melting points

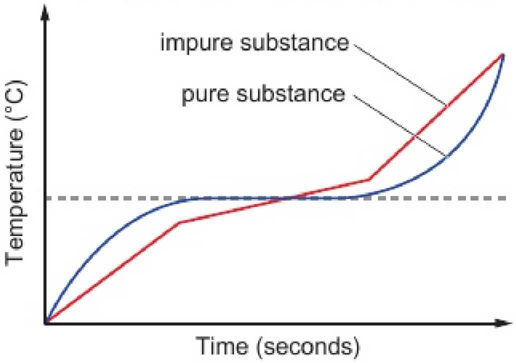
When a solid melts, its particles gain enough energy to overcome the weak forces of attraction between them. They move further away from one another and the solid becomes a liquid. The temperature at which this happens is the **melting point**. This is an example of a **physical property** (how a substance responds to forces and energy).

A pure substance has the same composition in every part of it, and so its physical properties are the same in every part. So, all of a pure substance will melt at the same temperature until all the substance has changed state. The melting point of pure gold is 1063 °C and the melting point of oxygen is –218 °C.

5th **5** What is the freezing point of pure oxygen?

C this sweet is a mixture and so does not have a sharp melting point

How temperature changes in a pure substance and an impure substance as they are heated



D heating curves for a pure substance and a mixture

The sweet shown in photo C has a liquid centre. The whole sweet melts over a *range* of temperatures and not all the parts melt and become liquid at the same time. This is what happens in mixtures – they do not have fixed, sharp melting points.

Substance	Melting temperatures (°C)
lead–tin alloy	183 to 258
argon	–189
carbon monoxide	–205

6 The table shows some melting temperatures.

5th **a** Identify which substances are mixtures and which are pure.

7th **b** Sketch a cooling curve for each of the three examples and explain their shapes.

Exam-style question

Explain why mixtures melt over a range of temperatures but pure substances have precise melting points. *(2 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 List the ways in which pure substances are different from mixtures.

Extend

E1 A piece of gold jewellery is 750 on the fineness scale. Would you expect the jewellery to have a sharp melting temperature? Explain your answer.

CC2b Filtration and crystallisation

Specification reference: C0.6; C2.7

Progression questions

- How can filtration be used to separate mixtures?
- How can crystallisation be used to separate mixtures?
- What are the hazards and risks when separating mixtures by filtration and crystallisation?

A Some whales filter sea water with bristles (called baleen plates) to separate krill from the water.

4th **1 a** Give one example of a mixture that can be separated by filtration.

5th **b** Explain how this mixture is separated by filtration.

4th **c** Describe another type of mixture that can be separated by filtration.

Did you know?

Nearly 4 million tonnes of salt are solution mined in the UK each year.

C Salt can be produced by the evaporation of sea water.

Filters can be used to separate some mixtures. They let smaller pieces or liquids through but trap bigger pieces or **insoluble** substances.

Examples of **filtration** are to be seen all around us. Cars, vacuum cleaners and air-conditioning systems all have filters. Some whales use filters to feed. They open their mouths and take in water. When they close their mouths, they push out the water through filters. Small animals (such as krill) get stuck in the filters and are swallowed.

Crystallisation

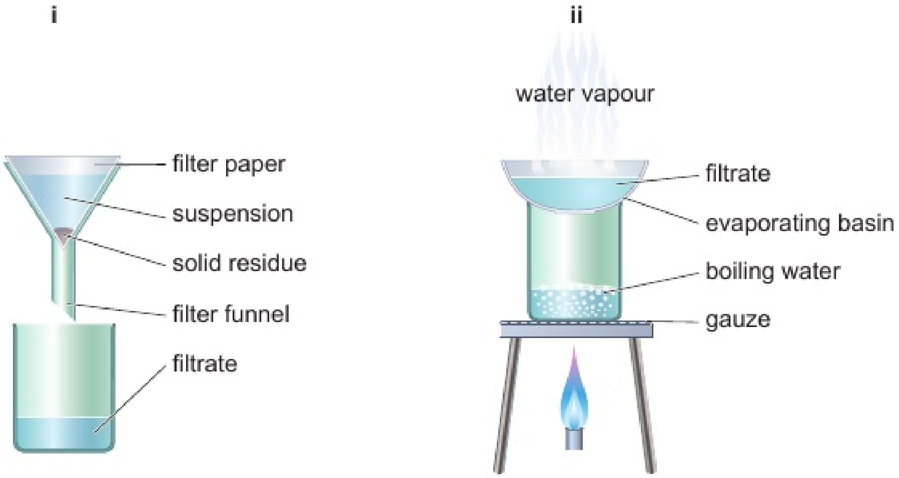
A **solution** is a mixture made of **solutes** (dissolved substances) in a liquid called the **solvent**. Solutes can be separated from a solution by evaporating the solvent to leave the solutes behind. This is called **crystallisation**. The process forms solid crystals of various sizes. If the crystals form slowly, the particles have longer to form an ordered pattern and will make larger crystals.

B Crystals in the Giant Crystal Cave in Mexico took over 500 000 years to form.

Table salt is produced from sea water, or is dug out of the ground or extracted using 'solution mining'. In this process water is pumped into layers of salt underground. The resulting salt solution is then heated, which evaporates the solvent and makes the solution more and more salty. Eventually it reaches a point where there is as much salt in the water as can possibly dissolve. This is a **saturated solution** and it contains the maximum amount of solute that can dissolve in that amount of solvent at that temperature. If more water evaporates and/or the solution cools, then some solute leaves the solution and salt crystals form.

Filtration and crystallisation in the lab

To filter a solution in the laboratory, a filter funnel is lined with filter paper that has fine holes in it. The solvent and solute(s) pass through the fine holes to form the **filtrate**. Bits of insoluble substances cannot fit through the holes and so leave a **residue** in the filter paper. A Bunsen burner is then used to evaporate the filtrate carefully. Care must be taken not to overheat the solution once it is saturated, because hot crystals may spit out. Further heating may also cause crystals to change chemically.



D Laboratory apparatus for (i) filtration and (ii) crystallisation.

In a **risk assessment**, the **hazards** of doing an experiment are identified. A hazard is something that could cause harm. Then ways of reducing the **risk** (chance) of a hazard causing harm are considered.

During crystallisation, the risks from spitting can be reduced by wearing eye protection, removing the Bunsen burner before the solution is completely dry and/or using steam to heat the evaporating basin gently (as above).

7 When a mixture of rock pieces, salt and water is filtered, what will be found as the:

a filtrate

b residue?

8 **a** List two of the hazards when carrying out filtration and crystallisation.

b Explain how the risks from each of your hazards can be reduced.

Exam-style question

Explain the difference between a risk and a hazard. *(2 marks)*

2 Give the names of two mixtures that can be separated by crystallisation.

3 In the solution mining of salt, give the names of the:

a solvent

b solution

c solute.

4 When is a solution said to be 'saturated'?

5 Explain why crystals form during crystallisation.

6 Explain why the crystals in photo B are so big.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Explain how you would separate sand *and* salt from a mixture of the two.

Extend

E1 Scientists looking for new substances in plants grind up the plants with methanol. This solvent dissolves many plant compounds. However, methanol is flammable and toxic (especially if the vapour is inhaled). Large crystals can be made to help scientists work out what the compounds are made of. Explain how you would make plant-compound crystals using methanol.

CC2c Paper chromatography

Specification reference: C2.7; C2.9; C2.10

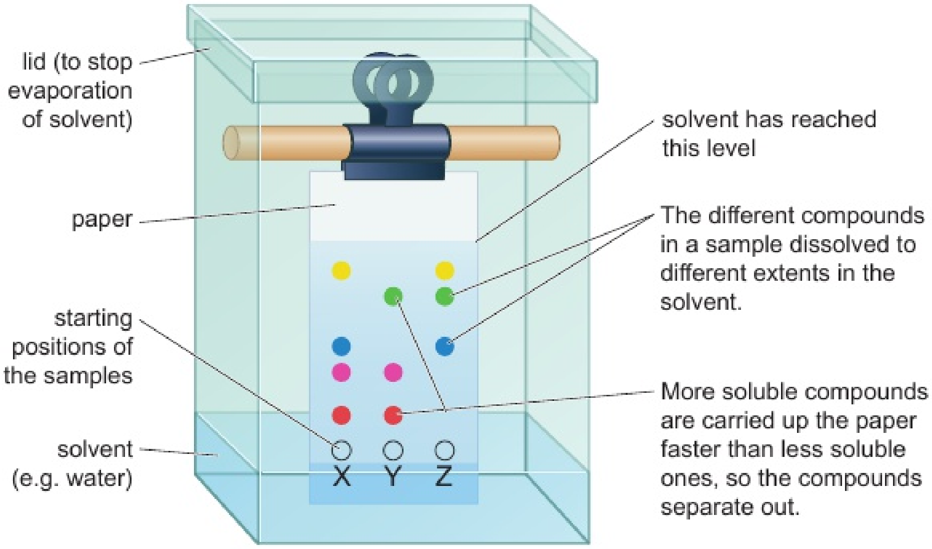
Progression questions

- How can chromatography be used to separate mixtures?
- What are the differences between mixtures and pure substances on a chromatogram?
- How do you calculate an R_f value?

A Experts restoring an old painting – they need to know what substances were mixed together to produce the paints used by the original artist.

Inks, paints and foods often contain mixtures of coloured compounds. **Chromatography** can be used to find out which coloured compounds the mixture contains. The type of chromatography used to analyse the substances in old oil paintings requires expensive machinery.

Paper chromatography is a simpler technique that works because some compounds dissolve better in a solvent than others. When a solvent moves along a strip of paper, it carries the different substances in the mixture at different speeds, so they are separated. The solvent is called the **mobile phase**. The paper contains the **stationary phase**, through which the solvent and dissolved substances move. The paper with the separated components on it is called a **chromatogram**.


lid (to stop evaporation of solvent)
paper
starting positions of the samples
solvent (e.g. water)
X
Y
Z
solvent has reached this level
The different compounds in a sample dissolved to different extents in the solvent.
More soluble compounds are carried up the paper faster than less soluble ones, so the compounds separate out.

B paper chromatography

5th **1** **a** How many different compounds are in substance X in diagram B?

6th **b** For mixture Y, explain why the green spot is higher than the red spot.

2 Look at diagram B again. Explain why:

5th **a** the labels for substances X, Y and Z are written in pencil, not ink

5th **b** the starting positions for the different substances are above the level of solvent in the container.

6th **3** One of the coloured compounds in diagram B has an R_f value of 0.1. Explain which compound this is likely to be.

The **R_f value** is the distance the compound has risen divided by the distance the solvent has risen. Both measurements are made from the starting positions of the samples on the paper.

$$R_f = \frac{\text{distance moved by the spot}}{\text{distance moved by the solvent}}$$

The R_f value of a particular compound does not change if the chromatography conditions used remain the same.

Worked example

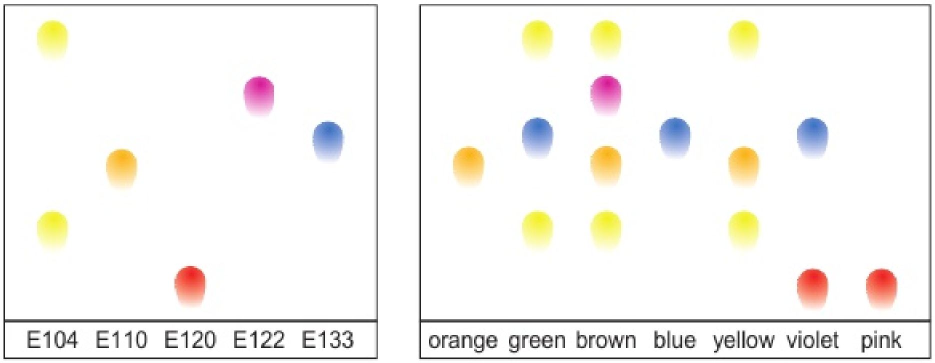
In diagram B, the pink spots have moved 4 cm and the solvent has moved 10 cm along the paper. Calculate the R_f value of this pink compound:

$$R_f = \frac{4}{10} = 0.4$$

A compound never rises as fast as the solvent, so R_f values are always less than 1. If you calculate an R_f value bigger than 1, you've made a mistake.

Paper chromatography can be used to:

- distinguish between pure and impure substances
- identify substances by comparing the pattern on the chromatogram with the patterns formed by known substances
- identify substances by calculating their R_f values.



C The chromatogram on the left was done using known substances. The chromatogram on the right shows that the orange and blue sweets contain single dyes.

4 In diagram B, the yellow spots have moved 9 cm and the solvent has moved 10 cm. Calculate the R_f value of the yellow substance.

5 In diagram C, the chromatogram on the left shows some food dyes found in sweets. The chromatogram on the right shows the results for some sweets.

a Which sweets contain just one dye?

b Which dyes are in the yellow sweets?

c What is the colour of the most soluble dye?

Did you know?

In 1983, many national newspapers paid a lot of money to publish diaries allegedly written by Adolf Hitler. However, scientists used chromatography to analyse the inks in the diaries and found that they were not available during Hitler's lifetime – the diaries were fake.

D Chromatography can be used to help identify substances at crime scenes.

Exam-style question

Two dyes have the same R_f values when tested using chromatography. Explain whether this means they are the same dye or not. *(3 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 The police have taken four orange lipsticks from suspects. Explain the steps needed to find out if one of the lipsticks could have made a mark at a crime scene.

Extend

E1 A laboratory produces a list of R_f values for food colourings. Explain why R_f values are used and what other information is needed for these R_f values to be useful.

CC2d Distillation

Specification reference: C0.6; C2.7

Progression questions

- What is distillation?
- How do simple distillation and fractional distillation differ?
- How would you reduce risks when carrying out a distillation experiment?

A a steam iron

2 In diagram B, what is the hazard if steam escapes from the tube?

3 Suggest a way of improving a simple still so that more of the steam condenses back to water.

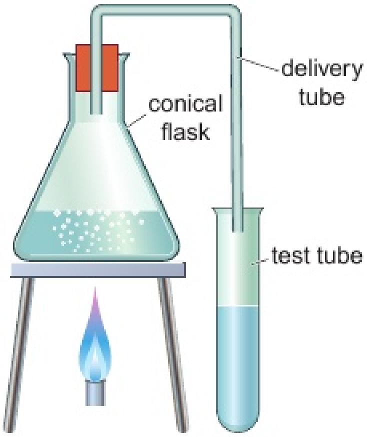
Tap water contains dissolved minerals, especially in hard water areas – tap water is a **mixture**. For some jobs it is best to use pure water (such as for chemical analysis, in car-cooling systems and older steam irons). To make water pure we need to separate it from the dissolved solids. This is done by **distillation**.

1 a What happens to the water in a steam iron when you turn the iron on?

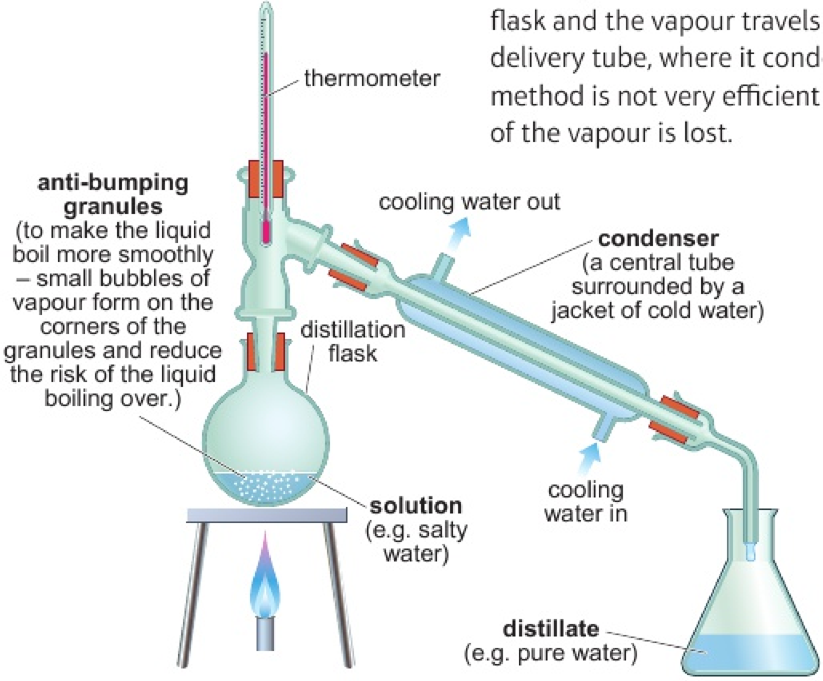
b Explain why some irons may not work well if you use ordinary tap water.

When mineral water **evaporates**, only the water turns to a gas (vapour). The solid minerals, which have much higher boiling points, are left behind. The water vapour (steam) is pure. If the vapour is then **condensed**, it turns back to liquid water again – the liquid water will now be pure. This combination of evaporation followed by condensation is called distillation. The apparatus used is called a **still**.

Diagram B shows a simple method for distilling. Water is heated in the conical flask and the vapour travels along the delivery tube, where it condenses. This method is not very efficient because much of the vapour is lost.



B a simple still


thermometer
anti-bumping granules
(to make the liquid boil more smoothly – small bubbles of vapour form on the corners of the granules and reduce the risk of the liquid boiling over.)
cooling water out
condenser
(a central tube surrounded by a jacket of cold water)
distillation flask
solution
(e.g. salty water)
cooling water in
distillate
(e.g. pure water)

C distillation apparatus

The type of still shown in diagram C is more efficient. The condenser keeps the tube cool, so that almost all of the vapour condenses and turns into a liquid.

4 Explain how the still in diagram C can be used to purify water.

5 Explain how:

a the condenser reduces the risk of hot vapour escaping

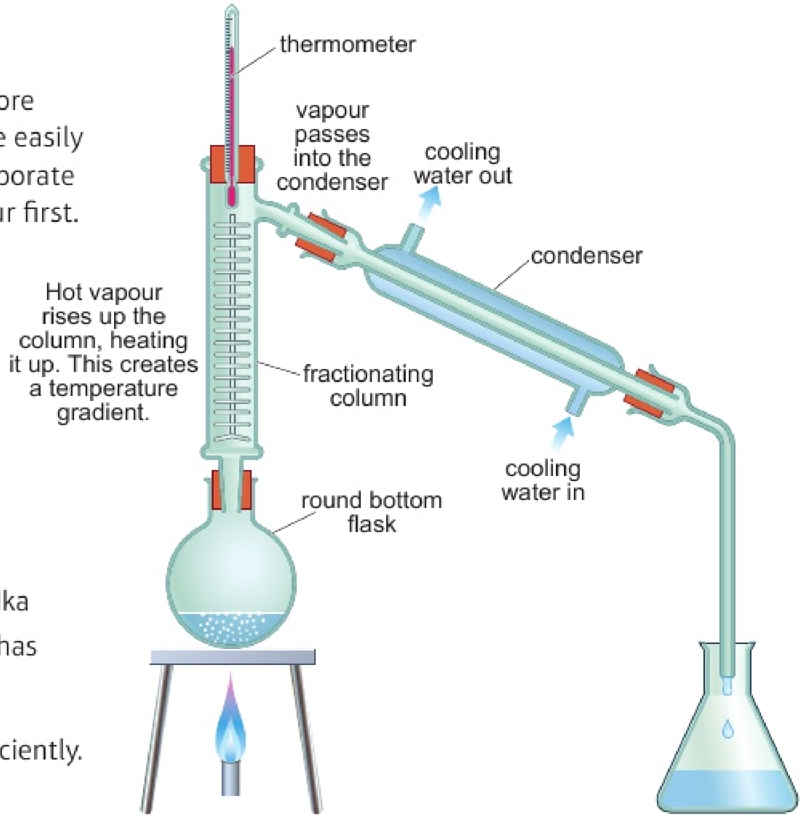
b the safety of the method is improved by using anti-bumping granules.

Fractional distillation

Distillation can also be used to separate two or more liquids. This works because some liquids boil more easily than others. Liquids with lower boiling points evaporate more easily than others, and will turn into a vapour first. This is called **fractional distillation**, because the original mixture will be split into several parts, or fractions. The first fraction to be collected contains the liquid with the lowest boiling point. The fractions could be pure liquids, or may still be mixtures.

Fractional distillation can be used:

- to separate the different products in crude oil
- to make alcoholic drinks such as whisky and vodka
- to separate out the gases in the air, after the air has been cooled and turned into a liquid at −200 °C.


thermometer
vapour passes into the condenser
cooling water out
condenser
Hot vapour rises up the column, heating it up. This creates a temperature gradient.
fractionating column
round bottom flask
cooling water in

D distillation apparatus with a fractionating column

Diagram D shows how to separate liquids more efficiently. A column is fixed above the distillation flask. The hot vapour rises up the column. At first, the vapour condenses when it hits the cool glass and drips back down into the flask. As the column gradually heats up, there will be a temperature gradient – it will be hottest at the bottom and the temperature will drop as you go further up the column. The fraction with the lowest boiling point will reach the top of the column first and the vapour will then pass into the condenser. If you keep heating, fractions with higher boiling points will then rise up the column and can be collected later.

8th **6** Compare and contrast simple and fractional distillation.

9th **7** Explain why a liquid with a lower boiling point will reach the top of a fractionating column more quickly than one with a higher boiling point.

Did you know?

The vacuum flask that we now use to keep drinks hot was originally used to keep liquid air *cold*. It was designed by James Dewar in 1892.

Exam-style question

A student is asked to separate two liquids. Liquid A boils at 100 °C and liquid B boils at 65 °C. The student sets up a fractional distillation experiment, and after a few minutes a clear liquid is collected from the condenser. Explain which of the two liquids will be collected first. *(2 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Explain what distillation is and how the distillation apparatus (the still) works. Use a labelled diagram to make your explanation clear.

S2 Explain the safety precautions you need to take when carrying out distillation in a laboratory.

Extend

E1 Pure ethanol ('alcohol') boils at 78.5 °C. Explain how a 50 : 50 mixture of ethanol and water can be separated by fractional distillation.

E2 Suggest why the boiling point of the starting liquid will change with time.

CC2d Core practical – Investigating inks

Specification reference: C2.11

Aim

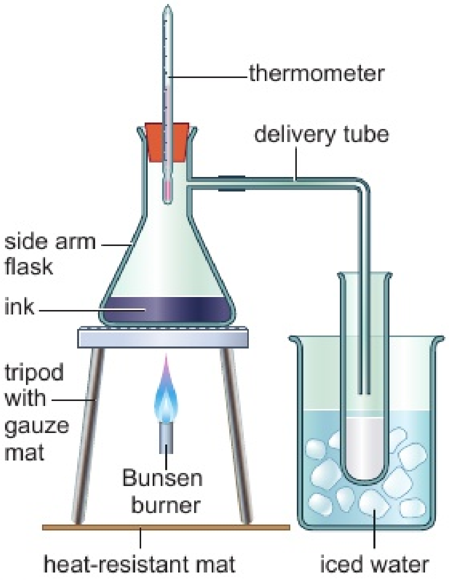
Investigate the composition of inks using simple distillation and paper chromatography.

A Fountain pen ink is available as a washable ink.

Ink is a mixture of coloured substances dissolved in a liquid solvent. Ink that appears to be a single colour, such as black, may contain two or more substances with different colours. Permanent inks do not run if the paper becomes wet, a useful property if you drop your homework in a puddle. Washable inks separate into their different colours if the paper gets wet, but may be removed if spilt on clothing.

Your task

You are going to use simple distillation to separate a sample of the solvent in some ink. You will also use paper chromatography to separate the coloured substances in samples of ink.



B separating ink using simple distillation

Method

Simple distillation

Wear eye protection.

A Set up your apparatus so that the ink is in a flask, and its vapours can be led away to be condensed. Diagram B shows some typical apparatus but yours may be different.

B Heat the flask of ink using a Bunsen burner, making sure the ink simmers gently and does not boil over into the delivery tube.

C Continue heating until you have collected a few cm^3 of distillate (distilled solvent).

D Note the maximum temperature obtained.

Paper chromatography

E Draw a pencil line on a piece of chromatography paper, about 2 cm from the bottom.

F Add a small spot of ink to the pencil line.

G Add water to a container to a depth of about 1 cm.

H Place the paper into the container. Make sure the paper is supported so that it does not slump into the water when it becomes damp. Allow the water to travel through the paper.

I Take the paper out before the water reaches the top. Immediately mark the position of the solvent front using a pencil, then leave the paper to dry.

J Measure the distance travelled by the water from the pencil line, and the distances travelled by each coloured substance.

K Calculate the R_f value for each coloured substance.

Exam-style questions

1 Explain the function of the beaker of iced water in diagram B. *(2 marks)*

2 A student carries out simple distillation on a sample of blue ink.

a Predict how the appearance of the ink changes, and give a reason for your answer. *(2 marks)*

b During the experiment, hot liquid solvent drips from the bulb of the thermometer. Suggest an explanation for a temperature rise from 83 °C to 100 °C as this happens. *(1 mark)*

3 Explain why simple distillation allows a pure solvent to be separated from a solution. *(3 marks)*

4 A student distils a sample of ink. Devise a simple method to show that the liquid collected is pure water. Include the expected results in your answer. *(3 marks)*

5 Propanone is a flammable solvent. A student carries out paper chromatography of ink using propanone.

a Identify the mobile phase and the stationary phase in her experiment. *(2 marks)*

b Explain one precaution necessary to control the risk of harm in her experiment. *(1 mark)*

c Suggest an explanation for why the level of the propanone should be below the ink spot on the paper at the start. *(1 mark)*

6 Explain how paper chromatography separates coloured substances in ink. *(3 marks)*

7 A student uses paper chromatography to analyse four samples of ink (X, A, B and C). Diagram C shows his results.

a Describe what the results tell you about ink sample X. *(2 marks)*

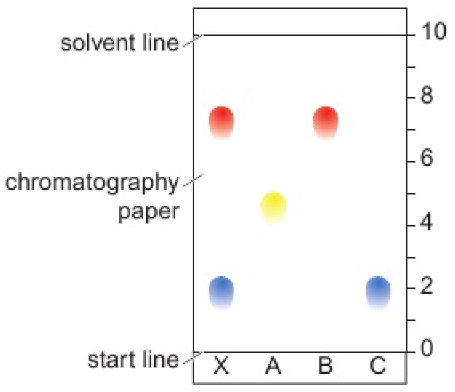
b Calculate the R_f value of the substance in ink B. *(2 marks)*

8 A student uses paper chromatography to analyse the dyes present in a sample of ink. She adds a sample of the ink and four dyes (1, 2, 3 and 4) to the paper. Table D shows her results for the dyes.

a Explain which dye is the most soluble in the solvent used by the student. *(2 marks)*

b Explain whether each dye is a pure substance. *(2 marks)*

c Suggest an explanation for why a mixture of dyes 1 and 4 may appear as a single green spot in a paper chromatogram. *(2 marks)*



C

Dye	Spot colour	R_f
1	yellow	0.10
2	red	0.35
3	green	0.67
4	blue	0.12

D

CC2e Drinking water

Specification reference: C2.8; C2.12

Progression questions

- How would you choose which method to use to separate a mixture?
- How is drinking water produced?
- Why must water used in chemical analysis be pure?

A Personal water purifiers filter water to make it safer to drink.

5th **1** Explain how pure water is produced using the apparatus shown in diagram B.

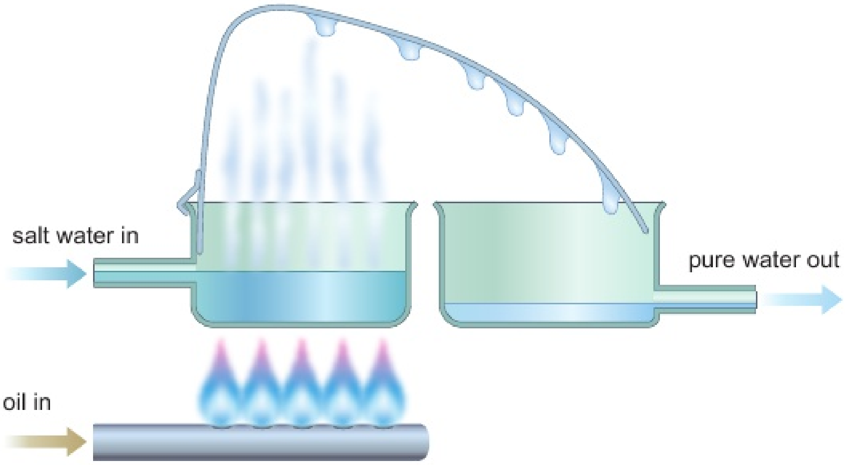
5th **2** Suggest why the simple distillation of sea water may be used to provide drinking water in oil-rich coastal countries.

C A cloudy white precipitate forming during a chemical analysis.

About 97% of the Earth's water is in the oceans. The concentration of dissolved salts in sea water is far too high for us to drink safely. Producing pure water from sea water is called **desalination** and can be achieved using **simple distillation**.

Purifying sea water

Water is separated from dissolved salts using simple distillation. Sea water is heated so that water vapour leaves it quickly. This vapour is then cooled and condensed, forming water without the dissolved salts.



B Simple distillation of sea water using oil as a fuel.

A lot of energy must be transferred to sea water during simple distillation, so it is not usually a suitable method for producing large volumes of drinking water. It is mainly carried out on a large scale where energy resources are cheap or plentiful, and where there is an abundant supply of sea water.

Water for chemical analysis

Chemical analysis involves using chemical reactions or sensitive machines to identify and measure the substances in a sample. The water used for chemical analysis should not contain any dissolved salts, otherwise incorrect results will be obtained. Tap water contains small amounts of dissolved salts, which may react to form unexpected cloudy **precipitates**. These may hide the correct result of the analysis. Also, the machines used for analysis may detect the salts, again leading to an incorrect conclusion.

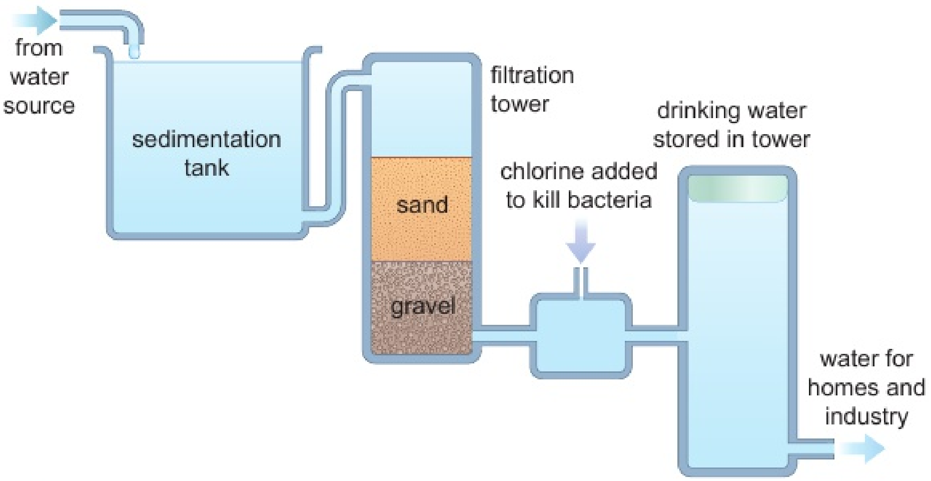
5th **3** Explain why distilled water is more suitable than tap water for doing a chemical analysis.

Water for drinking

In the UK, the raw material for producing drinking water comes from rivers, lakes or **aquifers** (underground rocks containing groundwater). The water in these sources is often stored in reservoirs, which are artificial lakes produced by building a dam across a valley. Fresh water from these sources contains:

- objects such as leaves and twigs
- small insoluble particles such as grit and silt
- soluble substances, including salts, pesticides and fertilisers
- bacteria and other microorganisms that may be harmful to health.

Different steps are needed to deal with these impurities. They include screening using a sieve, **sedimentation** (in which small particles are allowed to settle out) and filtration using tanks containing beds of sand and gravel. Chlorine is added in a process called **chlorination**. Chlorine kills microorganisms in the treated water.


from water source
sedimentation tank
filtration tower
sand
gravel
chlorine added to kill bacteria
drinking water stored in tower
water for homes and industry

D These are the main stages in treating fresh water to make it safe to drink.

4th **4** Explain why it may not be safe to drink water straight from a river.

4th **5** **a** Describe how water is treated to deal with leaves and twigs, grit and silt, and with microorganisms.

5th **b** Identify the stage missing from diagram D and draw a labelled diagram to show it.

6th **6** Suggest why chemical reactions, rather than separation methods, are used to remove harmful substances dissolved in drinking water in the UK.

Exam-style question

Fresh water is treated to make it safe to drink. Soluble and insoluble substances are removed during this treatment, and chlorine is added to kill harmful microorganisms. State two reasons why samples of the treated water are tested regularly. *(2 marks)*

Did you know?

Only about 2.5% of the Earth's water is fresh water. Of that, only 0.3% is in rivers and lakes – the rest is in icecaps, glaciers and ground water.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw flowcharts to describe two ways in which water can be made fit to drink.

Extend

E1 A bottle of water has a label saying 'Suitable for chemical analysis'. Describe how this water has been produced.

E2 Explain how you would check to see if this water really is suitable for analysis.

Methods of separating and purifying substances

A runny green mixture contains three compounds (**X**, **Y** and **Z**).

Compound	Melting point (°C)	Boiling point (°C)	State at room temperature	Notes
X	2435	4000	solid	not soluble in **Y** or **Z**
Y	−126	97.4	liquid	soluble in **Z**
Z	−114	78.4	liquid	soluble in **Y**

Plan a method to separate out **X**, **Y** and **Z**. Use the information in the table above and explain why you have suggested each step. (6 marks)

Student answer

Compound X is solid, and it is insoluble in the two liquids (Y and Z). This means it can be separated from them by filtration [1]*. When X is collected in the filter paper it will be wet with the two liquids, so it should be dried in a warm oven. The boiling points of the two liquids are well below the melting point of compound X, so compound X will not melt in the oven* [2].

The filtrate will be a mixture of compounds Y and Z. These can be separated using fractional distillation because their boiling points are different [3]*. When the mixture is heated, compound Z will distil off first because it has the lower boiling point* [4]*, leaving compound Y behind.*

[1] This explains *why* compound X can be separated by filtration.

[2] The answer uses information from the table to explain why drying compound X will work.

[3] This makes it clear which physical property fractional distillation depends on.

[4] It is clear which liquid will be collected first, and why.

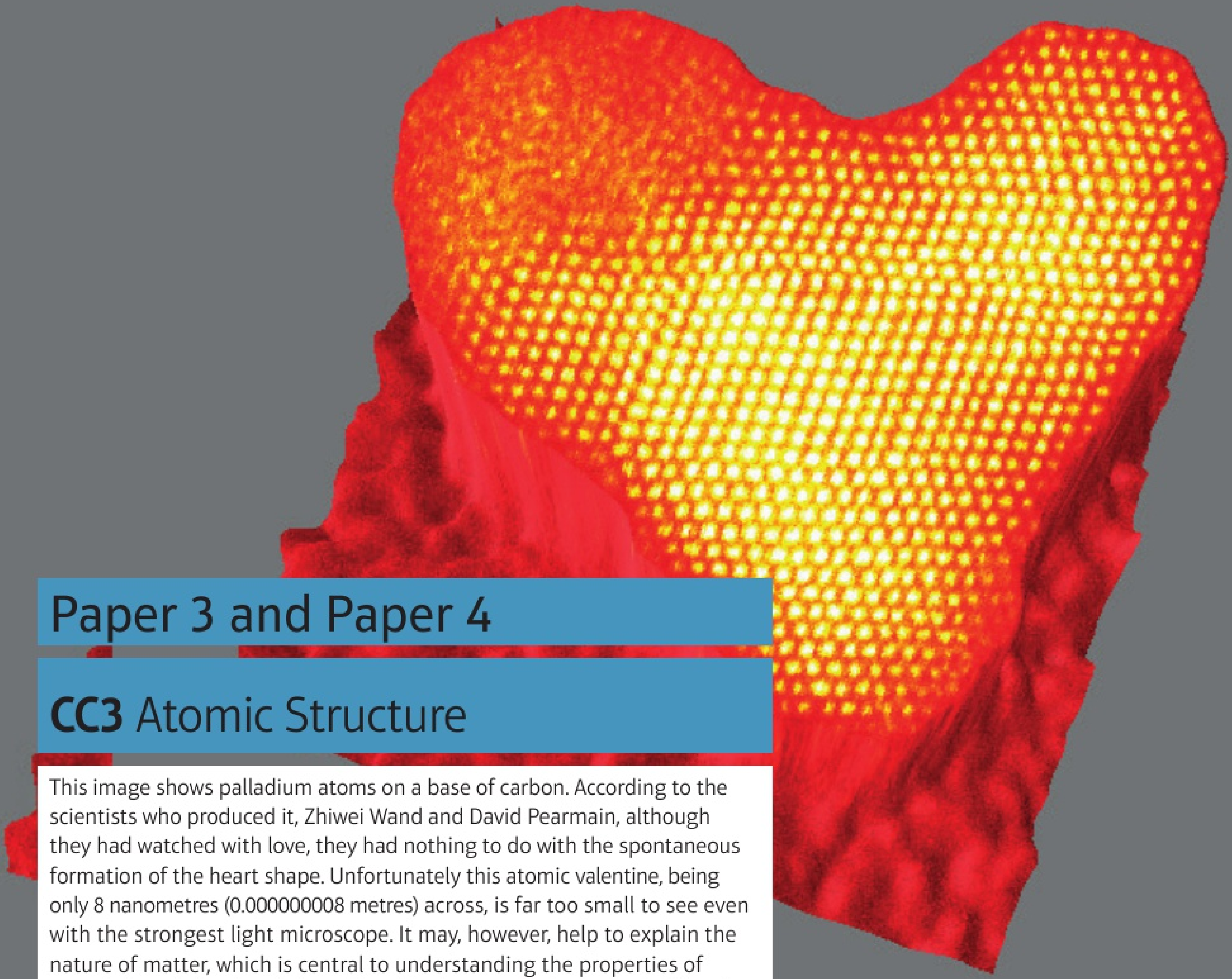
Verdict

This is a strong answer. It shows good knowledge and understanding of separation methods and uses correct scientific language.

The answer is organised logically, in the order that the practical would be carried out. Each step of the practical is linked to a scientific explanation.

Exam tip

If you are given a table of data or a graph in a question, make sure you use information from it in your answer.



Paper 3 and Paper 4

CC3 Atomic Structure

This image shows palladium atoms on a base of carbon. According to the scientists who produced it, Zhiwei Wand and David Pearmain, although they had watched with love, they had nothing to do with the spontaneous formation of the heart shape. Unfortunately this atomic valentine, being only 8 nanometres (0.000000008 metres) across, is far too small to see even with the strongest light microscope. It may, however, help to explain the nature of matter, which is central to understanding the properties of materials and the chemical reactions that form new substances. In this unit you will find out more about atoms and their structure.

The learning journey

Previously you will have learnt at KS3:

- about the particle model of matter
- how Dalton's ideas about atoms helped to explain the properties of matter
- how elements are arranged in the periodic table.

In this unit you will learn:

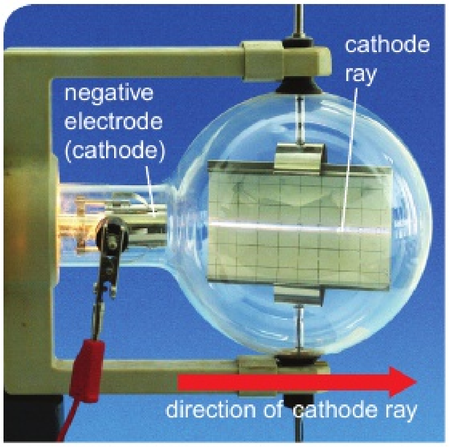
- how our ideas about atoms have changed
- what a relative atomic mass is
- **H** how to calculate relative atomic mass for an element.

CC3a Structure of an atom

Specification reference: C1.1; C1.2; C1.3; C1.4; C1.5

Progression questions

- How has the model of the atom changed over the last 200 years?
- How do the parts of atoms compare with each other?
- Why do atoms have no overall charge?



A a cathode ray tube

1 What are atoms?

2 Which of Dalton's ideas about particles is supported by the image of palladium atoms on the previous page?

In 1805 the English chemist John Dalton (1766–1844) published his atomic theory that said:

- all matter is made up of tiny particles called **atoms**
- atoms are tiny, hard spheres that cannot be broken down into smaller parts
- atoms cannot be created or destroyed
- the atoms in an **element** are all identical (but each element has its own type of atom).

Dalton's ideas helped to explain some of the properties of matter. However, experiments towards the end of the nineteenth century suggested that atoms contain even smaller particles.

When a high voltage is applied to a glass tube that has most of the air removed, glowing rays are seen. Some scientists thought that these 'cathode rays' were atoms leaving the negative electrode. In 1897, JJ Thomson (1856–1940) investigated the mass of the particles in the rays and found that they were about 1800 times lighter than the lightest atom (hydrogen). Cathode rays, therefore, did not contain atoms but **subatomic particles**, which we now call **electrons**.

The structure of atoms

Scientists have now worked out that atoms are made up of electrons together with heavier subatomic particles called **protons** and **neutrons**. All these particles have very, very small masses and electric charges. So, rather than use their actual masses and charges, it is easier to describe them by looking at their **relative masses** and **relative charges** compared to a proton. For example, if we say the mass of a proton is '1' then anything else that has the same mass is also '1'.

Did you know?

The actual mass of a proton is 0.000 000 000 000 000 000 000 001 67 g (1.67×10^{-24} g).

Subatomic particle	Relative charge	Relative mass
proton	+1 (positive)	1
electron	−1 (negative)	1/1835 (negligible)
neutron	0 (no charge)	1

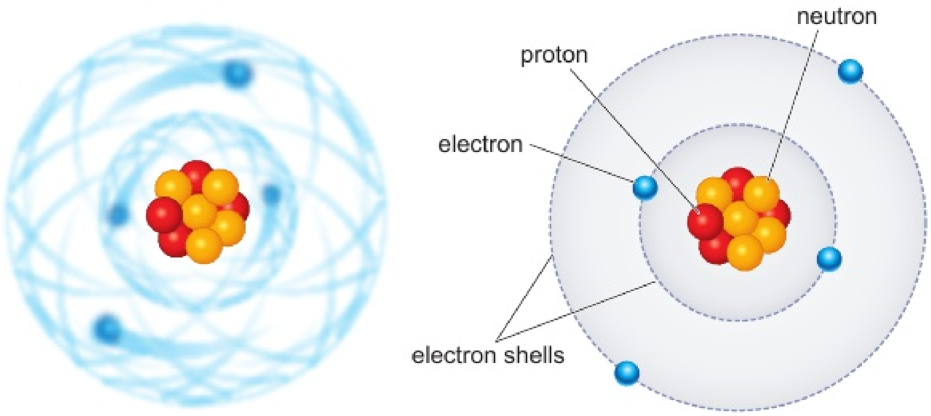
B relative masses and relative charges of subatomic particles

At the centre of all atoms is a tiny **nucleus** containing protons and neutrons. This is surrounded by fast moving electrons arranged in **electron shells** at different distances from the nucleus.

3 Which subatomic particle has the lowest mass?

Atoms in elements always have equal numbers of protons and electrons and so have no overall charge, because the charges cancel out.

Diagram C shows two ways of modelling a beryllium atom. The three-dimensional model attempts to show how we imagine electrons to move.



C The 'target diagram' on the right shows the arrangement of the electrons more clearly.

Models of atoms help us to understand their structure – but most models don't really give a correct impression of scale. The overall diameter of an atom can be 100 000 times the diameter of its nucleus.

D If an atom could be made the size of the Lord's cricket ground, its nucleus would be about the size of this dot ●. Most of an atom is empty space.

Exam-style question

Compare the modern model of an atom to the atomic model proposed by John Dalton in 1805. *(2 marks)*

4 How many protons, neutrons and electrons are in a beryllium atom?

5 A lithium atom has 3 protons, 4 neutrons and 3 electrons.

a Draw a diagram of this atom.

b Why is this atom neutral?

c How many electrons would be in an atom that has 17 protons?

Checkpoint

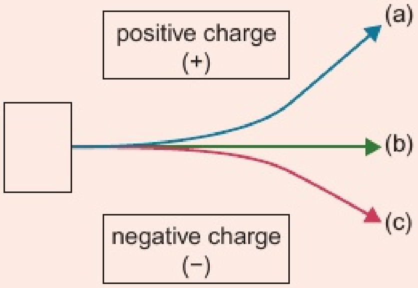
How confidently can you answer the Progression questions?

Strengthen

S1 Draw an atom and label it to describe the arrangement and properties of its subatomic particles.

Extend

E1 Figure E (below) shows what happens when the three subatomic particles are fired through an electric field.



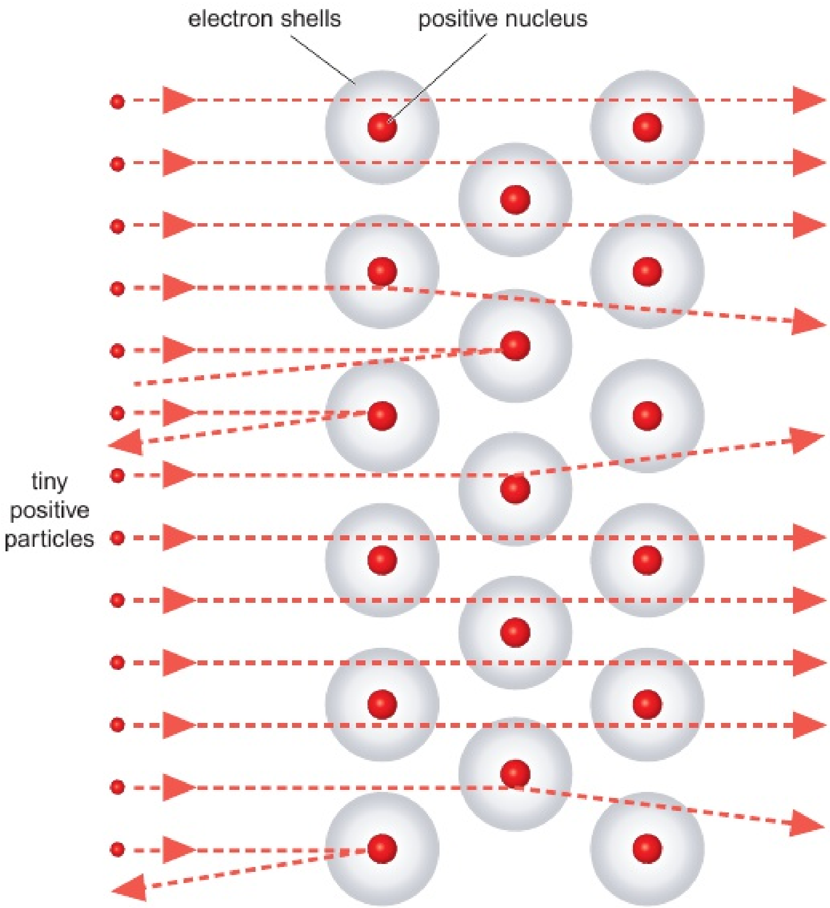
Name each particle a, b and c. Explain your answer.

CC3b Atomic number and mass number

Specification reference: C1.6; C1.7; C1.8; C1.10

Progression questions

- Why is most of the mass of an atom found in its nucleus?
- What does the atomic number tell you about an element?
- How can you calculate the numbers of protons, neutrons and electrons in atoms?



A Rutherford's scattering experiments suggested a nuclear atomic model.

The nuclear atom

In 1909, Ernest Rutherford (1871–1937) was working with others to investigate the structure of atoms. In one experiment, tiny positive particles were fired at a thin gold foil. To everyone's surprise most of the particles passed straight through the gold foil, with a few being deflected and a very small number bouncing back. Rutherford explained this by suggesting that atoms are mostly empty space, with a small positive central nucleus that contains most of the mass.

1 **a** Where is most of the mass of an atom?

b Explain how the experiment in diagram A suggests that atoms are mostly empty space.

Atomic number

The elements in the **periodic table** were originally placed in order of the masses of their atoms. However, this caused some elements to be grouped with others that had very different properties. So a few elements were swapped round to make sure that those with similar properties were grouped together, even if it meant that they were no longer in the correct order of mass.

Experiments by Henry Moseley (1887–1915) in 1913 confirmed that the rearranged order of elements in the table was actually correct. He showed that they were in order of the amount of positive charge in the nucleus. The proton was discovered about five years later. The modern periodic table places the elements in order of the number of protons in their atoms. This is the **atomic number** and it is this that defines an element – all the atoms of a particular element have the same unique atomic number.

Did you know?

Henry Moseley was killed during the First World War. As a result of Moseley's death, other important scientists were restricted from serving in front-line roles.

2 Carbon has an atomic number of 6. How many protons does it have?

3 Use a periodic table to find:

a the number of protons and electrons in atoms of:

i nitrogen **ii** potassium

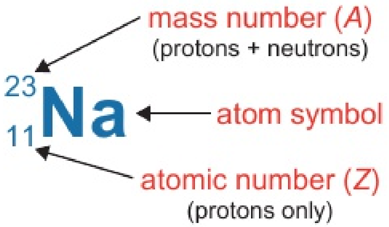
b two elements whose atomic mass order does not match their atomic number order.

4 In terms of structure, what do all atoms of a certain element have in common?

Mass number

The mass of an electron is described as 'negligible' – it is so small that it can be ignored. This explains why the nucleus of any atom contains nearly all its mass. For this reason the total number of protons and neutrons in an atom is called its **mass number**.

A mass number is represented by the symbol *A* and an atomic number by the symbol *Z*. These numbers are written next to an element's symbol as shown in diagram B.



B This is how scientists write the atomic number and the mass number for a sodium atom. It shows that the atom contains 11 protons and 12 neutrons in its nucleus.

5 How many protons, neutrons and electrons are in the atom $^{27}_{13}$Al? Explain how you worked out your answer.

6 A manganese atom has 25 protons, 30 neutrons and 25 electrons. Show this information using the form shown in diagram B.

7 Look at the 'Did you know?' box on this page. Which subatomic particle does a hydrogen atom *not* have? Explain your reasoning.

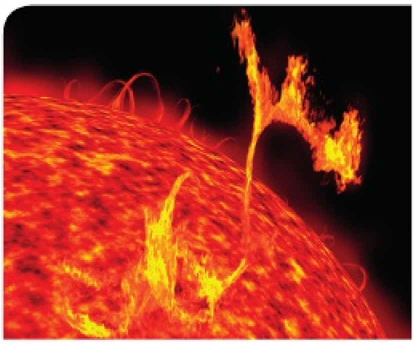
Exam-style question

Complete the table below *(2 marks)*

Atom	atomic number	mass number	number of protons	number of neutrons	number of electrons
X	90	222	90	132	(i)
Y	88	(ii)	88	134	88

Did you know?

Just two elements make up most of our Universe – about 74% is hydrogen $^{1}_{1}$H and 24% is helium $^{4}_{2}$H. These are also the two simplest atoms in the periodic table. The Sun releases energy by converting hydrogen atoms into helium atoms. Every second, over 600 million tonnes of hydrogen is converted to helium.



C

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 An atom can be represented in the form $^{65}_{29}$Cu. What does this tell you about this atom?

Extend

E1 Formulae can be written to connect the atomic number, mass number, and numbers of protons, electrons and neutrons in atoms.

For example:

atomic number = protons

Write formulae that connect the other four numbers.

CC3c Isotopes

Specification reference: C1.9; C1.10; C1.11; **H** C1.12

Progression questions

- How can you describe and identify isotopes of elements?
- Why are the relative atomic masses for some elements not whole numbers?
- **H** How do you calculate the relative atomic mass of an element?

1 **a** Write the name of each of the three lithium isotopes in diagram A.

b Describe each isotope in the format $^{A}_{Z}X$ (X is the element's symbol).

Did you know?

In 1945, at the end of the Second World War, two 'atomic bombs' were dropped on the Japanese cities of Hiroshima and Nagasaki. The bombs used nuclear fission and killed at least 129 000 people.

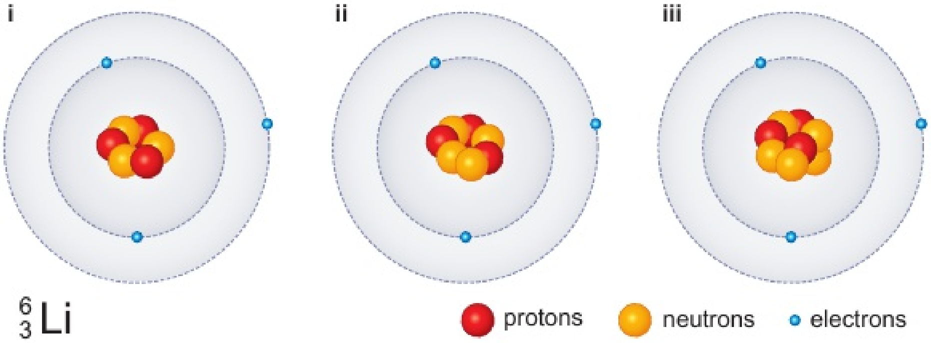
B

2 **a** State the numbers of protons and neutrons in an atom of uranium-235.

b State the number of protons, neutrons and electrons in the barium isotope formed in diagram C.

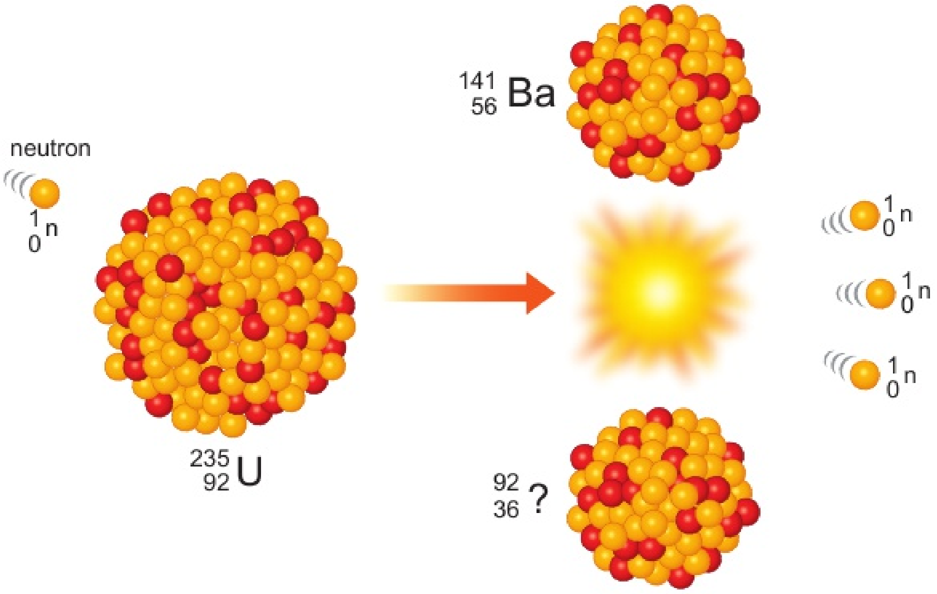
c Identify the other product. Give your answer using the format $^{A}_{Z}X$.

In 1932, James Chadwick (1891–1974) discovered the neutron. His discovery explains why some atoms of the same element have different masses. These atoms are known as **isotopes** – they have the same atomic number but different mass numbers. We refer to a specific isotope by adding its mass number to the element's name. The isotope on the left of diagram A is lithium-6.



A Isotopes of the same element are chemically identical because they have the same number of protons and electrons.

Understanding neutrons led to the discovery of nuclear energy. By firing neutrons at a uranium isotope, $^{235}_{92}U$, it was discovered that a nucleus can be split (**nuclear fission**). This produces new elements and transfers large amounts of energy. Nuclear power stations use the energy from nuclear fission to produce electricity.



C Nuclear fission can be started by firing neutrons at atoms of uranium-235.

Relative atomic masses

The mass of an atom is incredibly small, so we measure their masses *relative to* (compared to) an atom of carbon-12. This isotope is used as a standard and given a mass of exactly 12. The masses of all other atoms are compared to this. For example, the mass of helium-4 is one-third of that of carbon-12 and so its relative mass is 4.

3 How many $^{4}_{2}He$ atoms would be needed to balance the mass of the $^{24}_{12}Mg$ atom in diagram D?

4 Use the list of isotopes to answer the questions that follow.

$^{4}_{2}He$ $^{20}_{10}Ne$ $^{40}_{18}Ar$ $^{5}_{2}He$ $^{40}_{20}Ca$

Which two isotopes have the same:

a mass **b** chemical properties?

5 Write the mass ratios, in their simplest form, for the isotopes:

a $^{20}_{10}Ne$ and $^{40}_{18}Ar$ **b** $^{4}_{2}He$ and $^{20}_{10}Ne$

The relative mass of an isotope is its mass number. For example, chlorine has two isotopes, $^{35}_{17}Cl$ and $^{37}_{17}Cl$, and their relative masses are 35 and 37, respectively.

All elements exist as mixtures of isotopes. We use this idea to calculate an element's **relative atomic mass** (**RAM**) – the symbol is A_r. A relative atomic mass is the **mean** mass of an atom of an element compared with carbon-12. It takes into account all the isotopes of the element and the amounts of each. RAMs are not whole numbers (for example the A_r of chlorine is 35.5) but most values are commonly rounded to whole numbers. The RAM of an element and its atomic number are shown on the periodic table.

H

The abundances (overall proportions) of the two isotopes of chlorine are 75% of $^{35}_{17}Cl$ and 25% of $^{37}_{17}Cl$. We calculate the relative atomic mass of chlorine as follows.

If we take 100 atoms,
the relative atomic mass

$$= \frac{\text{total mass of the atoms}}{\text{the number of atoms}} = \frac{(75 \times 35) + (25 \times 37)}{100}$$

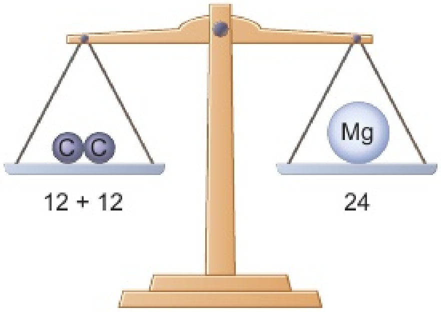
$$= \frac{2625 + 925}{100} = \frac{3550}{100}$$

$$A_r = 35.5$$

Exam-style question

Neon gas has a relative atomic mass of 20.2 and is made up of two atoms: $^{20}_{10}Ne$ and $^{22}_{10}Ne$. Explain which of these isotopes is the most abundant.

(3 marks)



D An atom of the isotope $^{24}_{12}Mg$ has twice the mass of $^{12}_{6}C$ and so has a relative mass of 24.

6 What does the relative atomic mass of an element tell you?

7 **H** Copper has two isotopes – 69% is $^{63}_{29}Cu$ and 31% is $^{65}_{29}Cu$. Calculate the RAM of copper. Give your answer to 1 decimal place.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

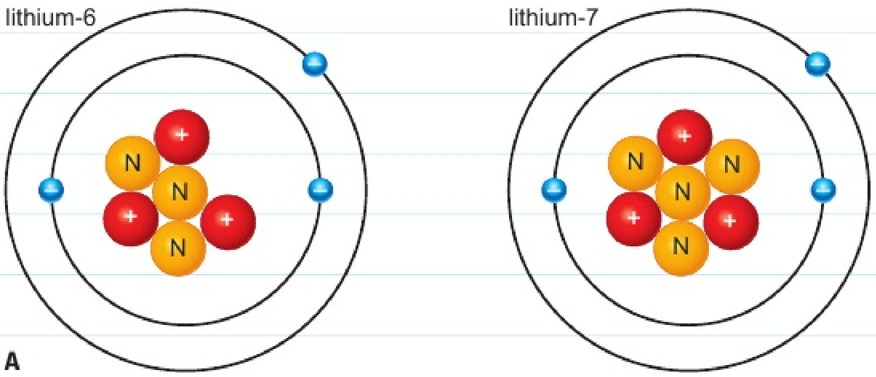
S1 Describe, with examples, the similarities and differences between isotopes of the same element.

Extend

E1 **H** Describing each step, work out the relative atomic mass of magnesium – it has the composition 79% ^{24}Mg, 10% ^{25}Mg and 11% ^{26}Mg.

Isotopes

The diagram below shows the structure of two isotopes of lithium.



Using these lithium atoms as examples, explain the similarities and differences in the properties of different isotopes of the same element. (6 marks)

Student answer

Atoms that are isotopes of the same element have the same atomic numbers but different mass numbers [1]. *This means they have the same number of protons and electrons but different numbers of neutrons* [2].

Atoms that are isotopes will chemically react in the same way [3] *but be different in structure* [4].

[1] The answer gives a basic definition of isotopes.

[2] This is a good description of the similarities and differences in the number of subatomic particles, but it doesn't use the lithium isotopes to illustrate the examples.

[3] This would be better if the answer explained *why* atoms of different isotopes react in the same way.

[4] This just repeats the earlier statement about differences, without adding any further detail.

Verdict

This is an acceptable answer. It contains a basic definition of isotopes, and a description of their similarities and differences in terms of structure. The answer also notes that the isotopes will have the same chemical properties. There is some linking of scientific ideas and a basic logical structure.

This answer could be improved by referring to the examples given in the question. It would have been better if the answer had included clearer definitions of 'atomic number' and 'mass number'. The answer should also link together some more scientific ideas. For example, it could have linked reactivity with electron configuration (to explain why isotopes of the same element have the same reactivity).

Exam tip

If an exam question asks you to use examples that are given, you must include them in your answer.

Paper 3 and Paper 4

CC4 The Periodic Table

There are over 100 known elements. The modern periodic table is a chart that arranges these elements in a way that is useful to chemists. Thanks to the periodic table, chemists can make sense of patterns and trends, which lets them predict the properties of elements. This works even if only a few atoms of an element exist. The periodic table shown here includes photos of most of the elements. If an element is very rare or difficult to obtain, it shows a photo of the relevant scientist or research laboratory involved in discovering or naming the element, or a diagram representing the arrangement of its electrons.

The learning journey

Previously you will have learnt at KS3:

- about chemical symbols for elements
- that Dmitri Mendeleev designed an early periodic table
- about periods and groups in the periodic table
- about metals and non-metals, their properties and their positions in the periodic table.

In this unit you will learn:

- how Mendeleev arranged the elements known at the time in a periodic table
- how Mendeleev predicted the existence and properties of undiscovered elements
- how Henry Moseley helped to confirm Mendeleev's ideas
- how the elements are arranged in the modern periodic table
- how to use the periodic table to predict and model the arrangement of electrons in atoms.

CC4a Elements and the periodic table

Specification reference: C0.1; C1.13; C1.14

Progression questions

- What are the symbols of some common elements?
- How did Mendeleev arrange elements into a periodic table?
- How did Mendeleev use his table to predict the properties of undiscovered elements?

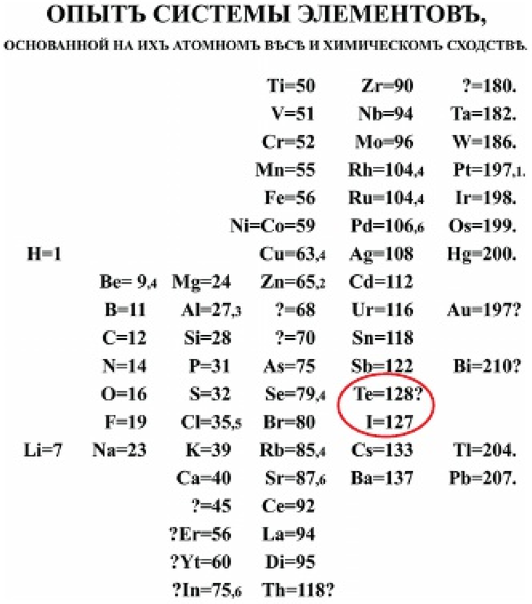
A Towels come in all sorts of sizes, colours and patterns, just as the elements have different properties. How would you organise them?

The Russian chemist Dmitri Mendeleev (1834–1907) faced a problem early in 1869. He was busy writing the second volume of his chemistry textbook and could not decide which elements it made sense to write about next. His solution was to construct a table that led to the **periodic table** we know today.

Organising elements

Chemists had discovered 63 elements by 1869, and they were keen to organise them in a helpful way. Mendeleev arranged these elements in order of increasing **relative atomic masses** (called atomic weights then). Unlike other chemists who had tried this before, Mendeleev did not always keep to this order, and he left gaps in his table.

Mendeleev sometimes swapped the positions of elements if he thought that better suited their **chemical properties** and those of their compounds. For example, fluorine, chlorine, bromine and iodine are non-metals that do not easily react with oxygen, whereas tellurium is a metal that burns in air to form tellurium dioxide. Iodine has a lower relative atomic mass than tellurium, so Mendeleev should have placed it before tellurium according to this **physical property**. Instead, he placed iodine after tellurium so that it lined up with fluorine, chlorine and bromine (elements with similar chemical properties to iodine). Even though Mendeleev used the most accurate relative atomic masses then available, he justified this swap by stating that the value for tellurium must be incorrect.



ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ,

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti=50	Zr=90	?=180.
			V=51	Nb=94	Ta=182.
			Cr=52	Mo=96	W=186.
			Mn=55	Rh=104,4	Pt=197,1.
			Fe=56	Ru=104,4	Ir=198.
			Ni=Co=59	Pd=106,6	Os=199.
H=1			Cu=63,4	Ag=108	Hg=200.
	Be= 9,4	Mg=24	Zn=65,2	Cd=112	
	B=11	Al=27,3	?=68	Ur=116	Au=197?
	C=12	Si=28	?=70	Sn=118	
	N=14	P=31	As=75	Sb=122	Bi=210?
	O=16	S=32	Se=79,4	Te=128?	
	F=19	Cl=35,5	Br=80	I=127	
Li=7	Na=23	K=39	Rb=85,4	Cs=133	Tl=204.
		Ca=40	Sr=87,6	Ba=137	Pb=207.
		?=45	Ce=92		
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75,6	Th=118?		

B Mendeleev's published 1869 table. The question mark after the relative atomic mass of tellurium, Te, shows that he thought this was incorrect. He swapped the positions of iodine and tellurium so that iodine ended up in the same line as other elements with similar properties.

Mendeleev assumed that elements would continue to be discovered, so he left gaps for them. This helped him to position the existing elements so that vertical columns contained elements with increasing relative atomic mass, and horizontal rows contained elements with similar chemical properties.

1 What information about the elements did Mendeleev use to produce his first table?

2 Explain why Mendeleev swapped the positions of iodine and tellurium in his table.

Making predictions

Mendeleev continued to work on his table. By 1871, he had settled on a table in which elements with similar properties were arranged into vertical columns, just as today.

Series	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
1	H 1							
2	Li 7	Be 9.4	B 11	C 12	N 14	O 16	F 19	
3	Na 23	Mg 24	Al 27.3	Si 28	P 31	S 32	Cl 35.5	
4	K 39	Ca 40	? 44	Ti 48	V 51	Cr 52	Mn 55	Fe 56 Co 59 Ni 59 Cu 63
5	(Cu 63)	Zn 65	? 68	? 72	As 75	Se 78	Br 80	
6	Rb 85	Sr 87	Y 88	Zr 90	Nb 94	Mo 96	? 100	Ru 104 Rh 104 Pd 106 Ag 108
7	(Ag 108)	Cd 112	In 113	Sn 118	Sb 122	Te 125	I 127	
8	Cs 133	Ba 137	Di 138	Ce 140				
9								
10			Er 178	La 180	Ta 182	W 184		Os 195 Ir 197 Pt 198 Au 199
11	(Au 199)	Hg 200	Tl 204	Pb 207	Bi 208			
12				Th 231		U 240		

C Mendeleev's 1871 table with his relative atomic masses. The red boxes are gaps left for elements not known at the time. Di, 'didymium', was later shown to be a mixture of two elements, neodymium and praseodymium.

Mendeleev used the gaps in his table to make **predictions** about the properties of undiscovered elements, based on the properties of nearby elements. One set of predictions was for an element he called eka-aluminium. When gallium was discovered shortly afterwards in 1875, its properties closely fitted those Mendeleev had predicted for eka-aluminium.

Property	Eka-aluminium, Ea	Gallium, Ga
relative atomic mass	about 68	70
density of element (g/cm³)	about 6.0	5.9
melting point of element (°C)	low	29.8
formula of oxide	Ea_2O_3	Ga_2O_3
density of oxide (g/cm³)	about 5.5	5.88
reacts with acids and alkalis?	yes	yes

D Mendeleev's predicted properties of eka-aluminium and the properties of gallium. He also successfully predicted the properties of scandium (discovered in 1879), germanium (1886) and polonium (1898).

Exam-style question

Suggest *two* reasons why other scientists did not accept Mendeleev's periodic table when it was first published. *(2 marks)*

Did you know?

A 313 km diameter crater on the far side of the Moon was named in honour of Mendeleev by the Russian scientists in charge of the Luna 3 space probe. The probe, launched in 1959, was the first to photograph the far side of the Moon. Element 101 is also named after Mendeleev.

3 Mendeleev amended the relative atomic masses of some elements between 1869 and 1871. Give the symbol of one element for which its value was approximately doubled.

4 Explain how Mendeleev's 1871 table shows he was unsure where to place three elements.

5 Explain why the discovery of gallium was seen as a successful test of Mendeleev's periodic table.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 What were the key features of Mendeleev's periodic table?

Extend

E1 How did Mendeleev think creatively to produce his table?

E2 What evidence supported Mendeleev's ideas?

CC4b Atomic number and the periodic table

Specification reference: C1.15; C1.16; C1.17; C1.18

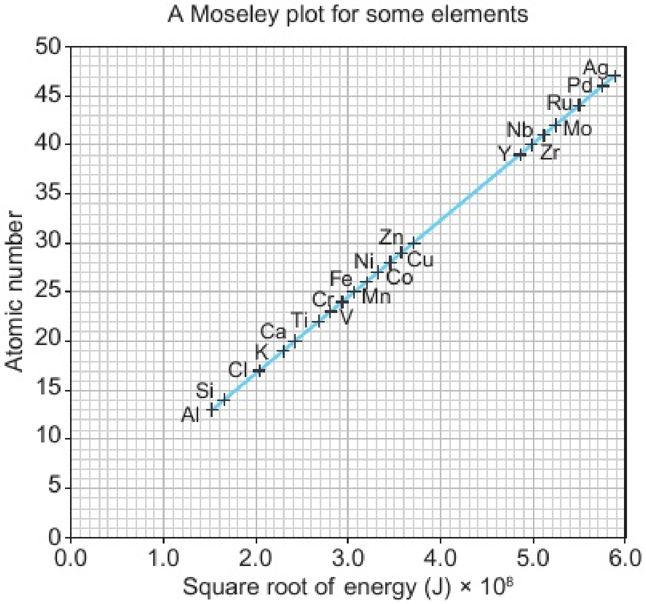
Progression questions

- Why was Mendeleev right to alter the order of some elements in his table?
- What is an element's atomic number?
- How are the elements arranged in the modern periodic table?

A The modern periodic table is easily recognised. There are many fun versions including this one advertising a science park.

Development of the periodic table continued after Mendeleev's first tables. An entire group of **inert** or very unreactive elements was discovered near the end of the 19th century. Even though chemists had not predicted their existence, they were easily fitted into the periodic table as group 0. However, pair reversals such as iodine and tellurium were not properly explained, and there were still gaps. This began to change in 1913 due to a physicist called Henry Moseley.

1 Suggest why chemists in Mendeleev's time did not predict the existence of group 0 elements such as neon.



B There is a linear relationship between atomic number and the square root of the energy of emitted X-rays.

Atomic number

When scientists were beginning to accept the periodic table, an element's atomic number was just its position in the table. Moseley showed instead that it is a physical property of an element's atoms. He fired high-energy electrons at different elements, which made them give off **X-rays**. Moseley discovered that for every step increase in atomic number there was a step change in the energy of these X-rays.

Moseley realised that an atomic number was equal to the number of positive charges in the nucleus of an atom. The particle that carries this charge, the proton, was discovered a few years later. So the **atomic number** must be the number of protons in a nucleus.

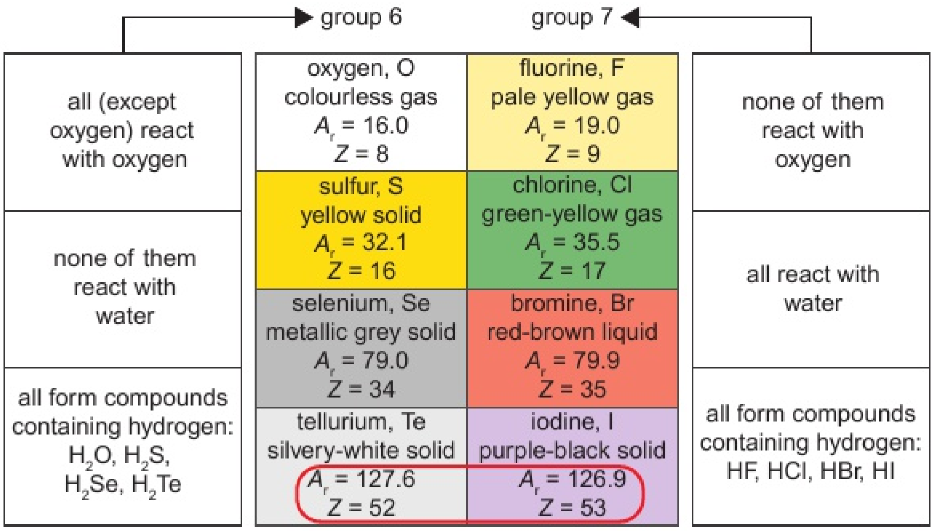
2 Describe the difference between Mendeleev's atomic numbers and Moseley's modern atomic numbers.

Pair reversals

The elements in the modern periodic table are arranged in order of increasing atomic number, *Z*. When this is done:

- elements in a row or **period** are in order of increasing atomic number
- elements with similar properties are in the same column or **group**
- non-metals are on the right of the table (the other elements are metals)
- the iodine–tellurium pair reversal is explained.

Iodine exists naturally as ^{127}I but tellurium has several different isotopes. About 20% of its atoms are ^{126}Te but nearly two-thirds of its atoms are ^{128}Te or ^{130}Te, so its **relative atomic mass** is greater than that of iodine.



group 6	group 7
oxygen, O colourless gas A_r = 16.0 Z = 8	fluorine, F pale yellow gas A_r = 19.0 Z = 9
sulfur, S yellow solid A_r = 32.1 Z = 16	chlorine, Cl green-yellow gas A_r = 35.5 Z = 17
selenium, Se metallic grey solid A_r = 79.0 Z = 34	bromine, Br red-brown liquid A_r = 79.9 Z = 35
tellurium, Te silvery-white solid A_r = 127.6 Z = 52	iodine, I purple-black solid A_r = 126.9 Z = 53

group 6	group 7
all (except oxygen) react with oxygen	none of them react with oxygen
none of them react with water	all react with water
all form compounds containing hydrogen: H_2O, H_2S, H_2Se, H_2Te	all form compounds containing hydrogen: HF, HCl, HBr, HI

C These are the elements in groups 6 and 7, each with its relative atomic mass, A_r, and atomic number, *Z*.

Filling gaps

More X-ray analysis showed that just seven elements between hydrogen (*Z* = 1) and uranium (*Z* = 92) were left to be discovered. These were all discovered between 1917 and 1945. Neptunium, the first element with an atomic number above 92, was discovered in 1940. Other such 'transuranium' elements continue to be discovered, and all can be placed in the periodic table.

6 Suggest why there is a gap between calcium, Ca, and titanium, Ti, in graph B.

Exam-style question

a Give an example, other than iodine and tellurium, of a pair of elements that would be in the wrong places if ordered by relative atomic mass. Use a periodic table to help you. *(1 mark)*

b Suggest why ordering by relative atomic mass would be incorrect. *(1 mark)*

Did you know?

Not all of Mendeleev's predictions were correct. For example, he predicted an element with an atomic weight of 0.4 that he called coronium. Moseley's work showed that it could not exist because it would need to contain part of a proton.

3 Give the relative atomic masses of tellurium and iodine to the nearest whole numbers.

4 Use information from diagram C to explain fully why Mendeleev was correct after all to place tellurium before iodine.

5 Use the periodic table at the back of the book to find the metals rubidium to tin, and the non-metals in groups 6 and 7. Describe the general positions of metals and non-metals.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 How are the elements arranged in the modern periodic table?

Extend

E1 What are the features of the modern periodic table?

CC4c Electronic configurations and the periodic table

Specification reference: C1.18; C1.19; C.1.20

Progression questions

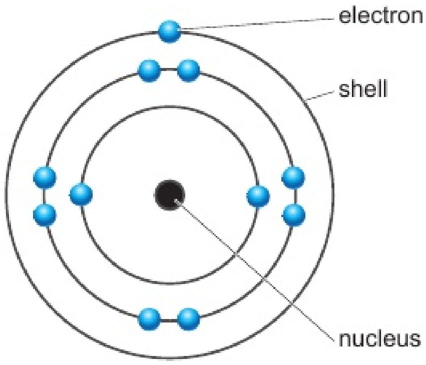
- What information does an electronic configuration give?
- How do you work out and show the electronic configuration of an element?
- How is the electronic configuration of an element related to its position in the periodic table?

A There are many pairs of empty seats on this bus. Where would *you* sit?

You have many choices where to sit on an empty bus but fewer choices when other people are already seated. **Electrons** fill shells in an atom, rather like filling a bus one seat at a time from the front.

Electron shells

In an atom, electrons occupy **electron shells** arranged around the nucleus. The shells can be modelled in diagrams as circles, with the electrons drawn as dots or crosses on each circle. The way in which an atom's electrons are arranged is called its **electronic configuration**. Sodium atoms each contain 11 electrons, and diagram B shows the electronic configuration for sodium.



B The electronic configuration of sodium shows three occupied shells.

Each shell can contain different numbers of electrons. For the first 20 elements (hydrogen to calcium):

- the first shell can contain up to two electrons
- the second and third shells can contain up to eight electrons.

Electrons occupy the shells, starting with the innermost shell and working outwards as each one becomes full. This is why, in a sodium atom, the first shell contains two electrons, the second shell contains eight electrons and the third shell contains one electron.

7th **1** State what is meant by the term 'electronic configuration'.

9th **2** Explain why the electrons in a sodium atom do not all occupy one shell.

Working out configurations

Electronic configurations can also be written out rather than drawn. For example, the electronic configuration for sodium is 2.8.1 – the numbers show how many electrons occupy a shell, and the full stops separate each shell.

You can work out the electronic configuration of an element from its atomic number, *Z*. The atomic number of chlorine is 17 – each chlorine atom contains 17 protons and so also contains 17 electrons.

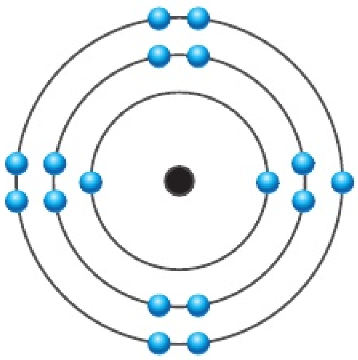
To fill a chlorine atom's shells:

- 2 electrons occupy the first shell (leaving 15 electrons)
- 8 electrons occupy the second shell (leaving 7 electrons)
- 7 electrons occupy the third shell.

The electronic configuration of chlorine is therefore 2.8.7 (diagram C shows this).

3 Describe how you can determine the atomic number, Z, of an element from its electronic configuration.

4 Write the electronic configuration of phosphorus, $Z = 15$.

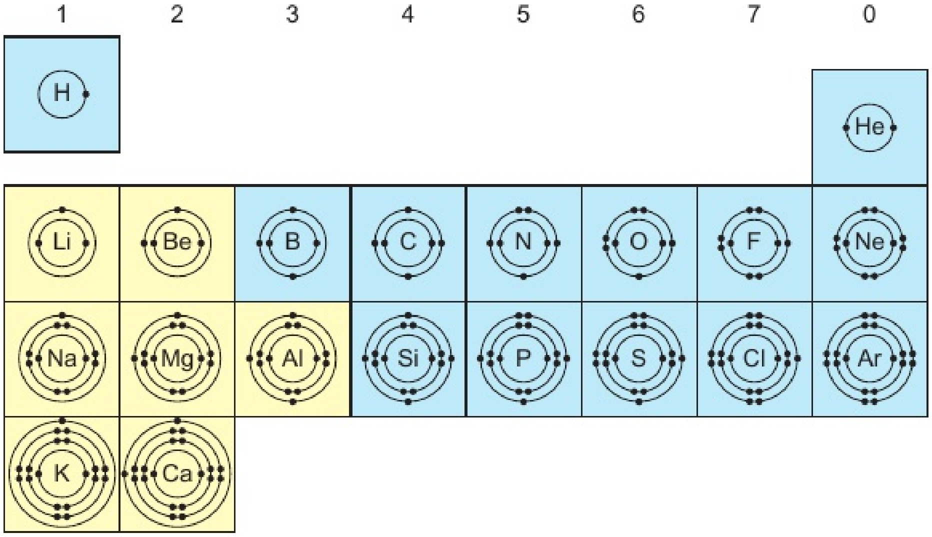


C The electronic configuration of chlorine shows three occupied shells.

Connections with the periodic table

Diagram D shows the electronic configurations for the first 20 elements in the periodic table. The electronic configuration of an element is related to its position:

- the number of occupied shells is equal to the period number
- the number of electrons in the outer shell is equal to the group number (except for group 0 elements, which all have full outer shells).



D These are the electronic configurations of the first 20 elements.

5 What do the electronic configurations of sodium and the other elements in group 1 have in common?

6 Explain how you can tell from their electronic configurations that sodium and chlorine are in the same period.

Exam-style question

Explain, in terms of electrons, why magnesium and calcium are in the same group in the periodic table. *(2 marks)*

Did you know?

After calcium, the third and fourth electron shells can actually contain up to 18 electrons. For this reason the International Union of Pure and Applied Chemistry (IUPAC) now recommends the use of group numbers in the range 1 to 18. In this newer numbering system, group numbers 3 to 12 refer to the block of elements between calcium and gallium. Group numbers 13 to 17 refer to the older group numbers 3 to 7, and 18 refers to group 0.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 How do you work out the electronic configuration of an element?

Extend

E1 How is the electronic configuration of an element determined, and related to its position in the periodic table?

Atomic structure and the periodic table

The table shows information about tellurium and iodine.

Element	Atomic number	Relative atomic mass, A_r
tellurium	52	127.6
iodine	53	126.9

A

Describe how Mendeleev arranged the elements known to him into a periodic table, and compare this with the arrangement in the modern periodic table.

In your answer, use information from the table above to provide examples. (6 marks)

Student answer

Mendeleev arranged the elements in order of relative atomic mass [1]*. He also used the properties of elements and their compounds, so he sometimes had to swap elements. For example, the A_r of iodine is 126.9, so he should have put iodine first* [2]*, but he put it second. He did this so it went into the same column as similar elements* [3].

In the modern periodic table, elements are arranged in order of increasing atomic number (the number of protons in the nucleus) [4]*. This explains why Mendeleev was correct when he placed tellurium before iodine.*

[1] This shows knowledge of how Mendeleev ordered the elements, but it should say 'in order of *increasing* relative atomic mass'.

[2] The answer should be supported by comparing the A_r values for the two elements.

[3] An element in the same group, such as chlorine, could be identified using the periodic table.

[4] It is a good idea to give clear definitions like this.

Verdict

This is an acceptable answer. It shows good knowledge and understanding of the periodic table and the answer is organised in a logical way. The student has linked their knowledge of atomic structure with an understanding of Mendeleev's periodic table.

The answer could be improved by clearly quoting examples from the information given in the table. For example, in the last paragraph the answer could have included the atomic numbers for each of the elements.

Exam tip

If you are asked to use information from the question as part of your answer then make sure you include the information. It is important to make sure you *use* the information in your answer – don't just repeat what you have been given.

Paper 3 and Paper 4

CC5 Ionic Bonding / **CC6** Covalent Bonding / **CC7** Types of Substance

Using an extremely powerful 'atomic force microscope' scientists at the Berkeley Lab in California produced this amazing image showing the positions of the bonds holding the atoms of a small molecule together. Using this technique, the scientists were also able to examine the breaking and reforming of bonds during a chemical reaction. Bonds are the fundamental forces of attraction that hold our universe together. Understanding how bonds are formed and broken is essential in helping us explain even the simplest physical change or chemical reaction.

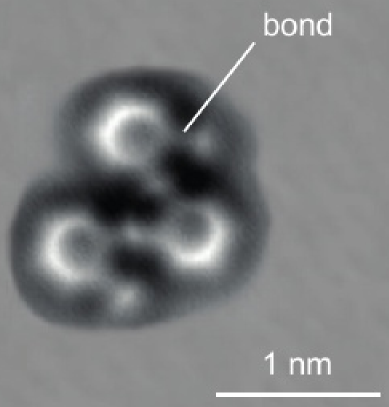
The learning journey

Previously you will have learnt at KS3:

- about the particle model of matter
- how Dalton's ideas about atoms and molecules helped to explain the properties of matter
- how elements are arranged in the periodic table.

In this unit you will learn:

- how ionic, covalent and metallic bonds are formed
- about the formation of lattice and molecular structures
- how the physical properties of a substance are linked to its bonding and structure.

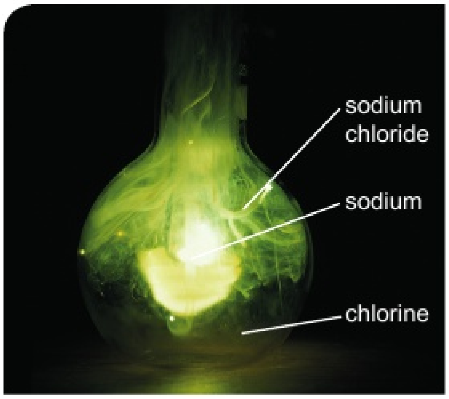


CC5a Ionic bonds

Specification reference: C0.1; C1.21;C1.22; C1.23; C1.24

Progression questions

- How are ions formed?
- How can the numbers of subatomic particles in an ion be calculated?
- What is an ionic bond?

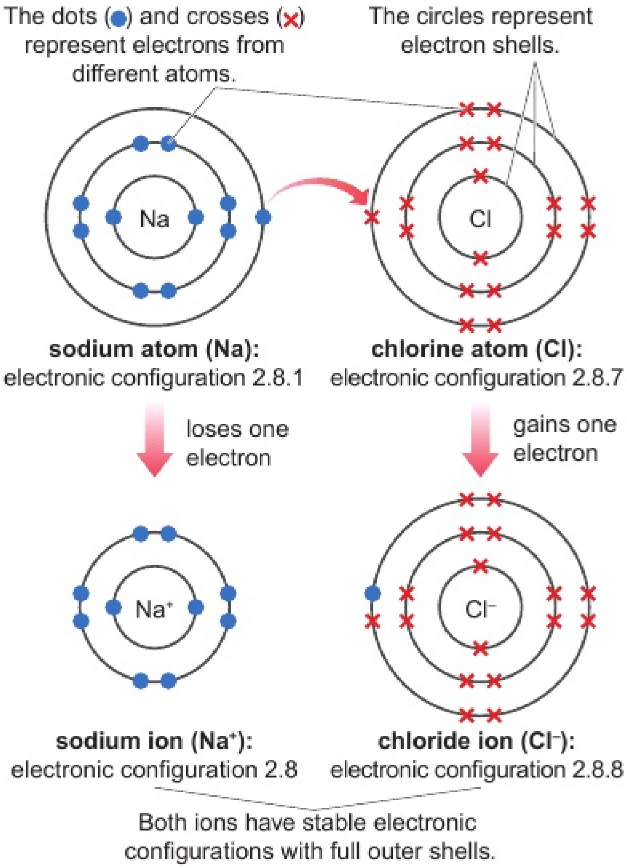


A Explosions can occur when new bonds form between sodium and chlorine atoms to form sodium chloride.

Bonds are forces of attraction that hold atoms together. When bonds form between atoms, energy is released from the atoms, making them more stable (less reactive). The most stable atoms are those of the noble gases, and scientists have found that this is because they have outer electron shells that contain as many electrons as possible – the outer shell of a noble gas atom is full.

Noble gas	Electronic configuration
He	2
Ne	2.8
Ar	2.8.8

B Atoms of all of the elements in group 0 have a stable electronic configuration (arrangement of electrons) with a complete outer shell of electrons.


The dots (●) and crosses (×) represent electrons from different atoms.
The circles represent electron shells.
Na
Cl
sodium atom (Na): electronic configuration 2.8.1
chlorine atom (Cl): electronic configuration 2.8.7
loses one electron
gains one electron
Na⁺
Cl⁻
sodium ion (Na⁺): electronic configuration 2.8
chloride ion (Cl⁻): electronic configuration 2.8.8
Both ions have stable electronic configurations with full outer shells.

C Dot and cross diagrams can be used to show what happens when ions are formed.

Atoms are more stable if they have an outer electron shell that is full, like a noble gas. This can happen by the transfer of electrons between atoms, forming charged particles called **ions**.

Metal atoms tend to lose electrons and form positive ions, called **cations**. Cations have more protons than electrons. Non-metal atoms tend to gain electrons and form negative ions, called **anions**. Anions have more electrons than protons. The formation of sodium (Na^+) and chloride (Cl^-) ions is shown in diagram C. Note that when non-metals form negative ions the end of the name changes to –ide.

1 **a** What are ions?

b State the difference between a cation and an anion.

There are forces of attraction between all positively and negatively charged objects. These are called **electrostatic forces**. These forces hold the oppositely charged ions together, and form an **ionic bond** between them.

2 **a** What is happening to the atoms when they form ions?

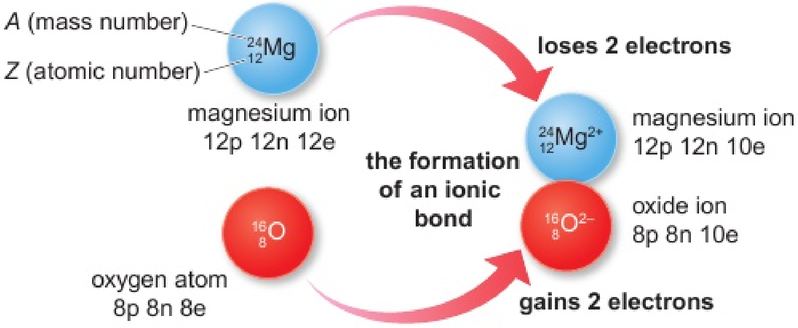
b What holds the ions together in an ionic bond?

Atoms that easily form ions will have either a nearly full or a nearly empty outer electron shell. Most ionic bonds are formed between a metal and a non-metal. Table D shows the number of electrons lost or gained and the resulting ion charge of some groups of elements. The ion formed depends on the element's position in the periodic table and its number of outer electrons.

	Group 1	Group 2	Group 6	Group 7
outer electrons	1	2	6	7
electrons lost or gained	1 lost	2 lost	2 gained	1 gained
charge on ion	1+	2+	2−	1−
example	Li^+	Ca^{2+}	S^{2-}	F^-

D formation of ions by elements in groups 1, 2, 6 and 7

Diagram E shows the number of protons, neutrons and electrons in each atom and ion in the formation of the ionic bond in magnesium oxide.



E ionic bond formation in magnesium oxide

5 An aluminium atom $^{27}_{13}Al$ loses three electrons when its ion is formed.

9th **a** How many protons, neutrons and electrons are in the aluminium ion?

7th **b** Write the symbol for the aluminium ion.

8th **6** Draw dot and cross diagrams to show the ions in diagram E.

Exam-style question

Bromine is in group 7 of the periodic table.

a Write the symbol for a bromide ion. *(1 mark)*

b State what the symbol tells you about the electrons in a bromide ion compared with a bromine atom. *(1 mark)*

Did you know?

The most common atom in the Universe, hydrogen, contains one proton and one electron. The hydrogen ion (H^+) is therefore just a proton. This makes it more than 100 000 times smaller than the hydrogen atom and it is the smallest particle that can take part in a chemical reaction.

3 Write the symbol for the ion formed by:

7th **a** potassium (K) in group 1

7th **b** selenium (Se) in group 6.

4 A sulfur atom contains 16 protons.

8th **a** How many electrons does it contain?

9th **b** Write out its electronic configuration.

9th **c** Explain why it forms S^{2-} ions.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe what happens when lithium (group 1) and fluorine (group 7) react to form an ionic bond.

Extend

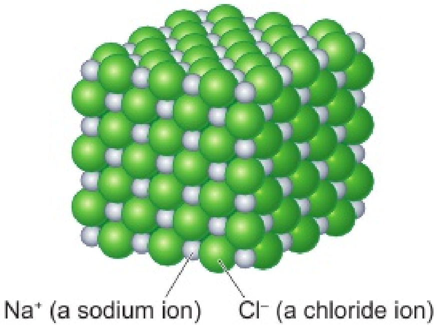
E1 Using dot and cross diagrams, explain what happens when aluminium and oxygen form an ionic bond.

CC5b Ionic lattices

Specification reference: C0.1, C1.25, C1.26, C1.27

Progression questions

- What is an ionic lattice?
- What do the endings –ide and –ate tell you about a substance?
- How do you work out the formulae of ionic compounds?



A Sodium chloride forms a cubic lattice structure.

2 Explain why the solid shown in photo B can be described as crystals.

B Sodium chloride crystals are shaped like cubes. These crystals are from a salt mine in Poland and the largest one has sides of 5 cm.

Ionic compounds, which are formed by the loss and gain of electrons, are held together by strong electrostatic forces of attraction between oppositely charged ions. These strong ionic bonds allow 'billions' of ions to be packed together in a regular repeating arrangement called a **lattice structure**. The lattice structure in sodium chloride is shown in diagram A.

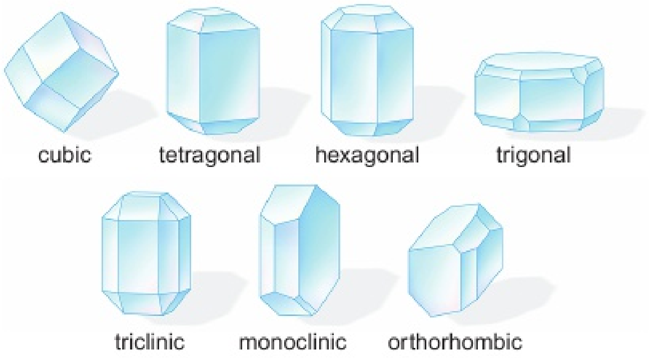
1 **a** What holds ions together in an ionic bond?

b Why is the structure in diagram A described as a cubic lattice?

Ionic compounds will often form **crystals** when solid because of their regular lattice structure. Crystals are pieces of solid that have a particular regular shape, flat surfaces and sharp edges. Photo B shows crystals of sodium chloride.

Did you know?

The shapes of crystals are determined by the structure of the lattice. There are seven basic crystal or lattice structures.



C the seven basic crystal structures

Positive ion	Ion formula	Negative ion	Ion formula
sodium	Na^+	fluoride	F^-
lithium	Li^+	chloride	Cl^-
potassium	K^+	bromide	Br^-
magnesium	Mg^{2+}	oxide	O^{2-}
calcium	Ca^{2+}	sulfide	S^{2-}
aluminium	Al^{3+}	phosphide	P^{3-}

D common ions

Working out ionic formulae

Ionic compounds are electrically neutral (they have no overall charge). So the formula of an ionic compound contains the same number of positive charges as negative charges. To work out ionic formulae we will need to use ion formulae, as shown in table D. Note that in two-element compounds the name ending of the non-metal ion is changed to –ide.

Worked example W1

Magnesium oxide contains the ions Mg^{2+} and O^{2-}.

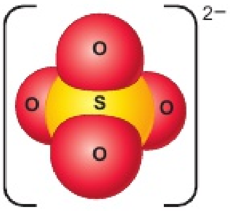
A magnesium ion has two positive charges and an oxide ion has the same number of negative charges. One of each ion will balance the charges, and so the formula = MgO

Worked example W2

Sodium sulfide contains the ions Na^{+} and S^{2-}.

Therefore two Na^{+} ions are needed to balance the charges on the S^{2-} ion, and so the formula = Na_2S

Some ions contain more than one atom. For example, the sulfate ion, shown in diagram E, contains one sulfur atom bonded to four oxygen atoms with two added electrons. More examples of these **polyatomic ions** are shown in table F. An ion name ending '–ate' or '–ite' shows that the ion contains oxygen as well as another element.



E The formula of a sulfate ion is SO_4^{2-}.

If an ionic formula contains two or more of the same polyatomic ions then the formula of the polyatomic ion must be written inside brackets.

Worked example W3

Calcium nitrate contains the ions Ca^{2+} and NO_3^-.

Therefore two NO_3^- ions are needed to balance the charges on the Ca^{2+} ion, and so the formula = $Ca(NO_3)_2$

Note that the brackets are needed around the polyatomic ion. Without brackets the formula becomes $CaNO_{32}$ and this compound is not possible.

5 Write the formulae for:

a sodium carbonate **b** ammonium sulfate.

6 Li_3PO_4 is an ionic compound.

a Suggest a name for this compound.

b Write the formulae for both of the ions.

Exam-style question

Potassium iodide and potassium iodate, which contains the ion IO_3^-, are both used in health supplements.

a Give the formulae for both compounds. *(1 mark)*

b Compare and contrast these two compounds. *(2 marks)*

3 Write the formulae for:

a sodium fluoride

b calcium sulfide

c magnesium bromide

d aluminium oxide.

4 The formula of iron chloride is $FeCl_3$.

a What is the charge on the iron ion?

b Explain how you worked out your answer.

Polyatomic ion name	Ion formula
ammonium	NH_4^+
nitrate	NO_3^-
hydroxide	OH^-
carbonate	CO_3^{2-}
sulfate	SO_4^{2-}
sulfite	SO_3^{2-}

F Polyatomic ions are groups of two or more atoms, which have become charged.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe with the help of a diagram the type of structure you find in ionic compounds.

Extend

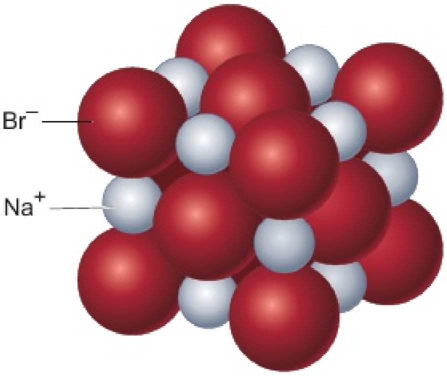
E1 What does the formula $Fe_3(PO_4)_2$ tell you about the compound and its structure?

CC5c Properties of ionic compounds

Specification reference: C1.33

Progression questions

- What particles and forces are present in ionic compounds?
- Why do ionic compounds have high melting points and boiling points?
- Why do ionic compounds conduct electricity when they are liquids or dissolved in water but not when they are solids?



A the lattice structure of sodium bromide

All ionic compounds contain charged particles called ions. Ions have one or more positive charges or one or more negative charges. The oppositely charged ions in ionic compounds are held together by strong electrostatic forces of attraction, which we call ionic bonds. It is important to remember that ionic compounds contain *ions*, not atoms or molecules.

In ionic compounds, huge numbers of ions are arranged in a giant structure or lattice. This has a regular pattern and so ionic compounds form crystals.

5th **1** State the type of particles present in an ionic compound.

5th **2** State the type of forces found in an ionic bond.

B molten sodium chloride

Melting points and boiling points

The electrostatic forces of attraction between oppositely charged ions are strong. A lot of energy is needed to overcome these forces in order to separate the ions and cause the substance to melt. This is why ionic compounds must be heated to high temperatures before they change state. They have high melting points and boiling points.

Some ions have more than one charge (such as Mg^{2+} and O^{2-}). These highly charged ions will attract other ions more strongly than ions with one charge. More energy will be needed to overcome the electrostatic forces of attraction and so the melting points will be higher.

Ionic compound	Melting point (°C)	Boiling point (°C)
sodium bromide, NaBr	747	1390
sodium chloride, NaCl	801	1413
magnesium oxide, MgO	2852	3600

C Ionic compounds have high melting points and boiling points.

7th **3** Explain why ionic compounds have high melting points.

8th **4** Explain why magnesium oxide has a much higher melting point than sodium chloride.

Electrical conductivity

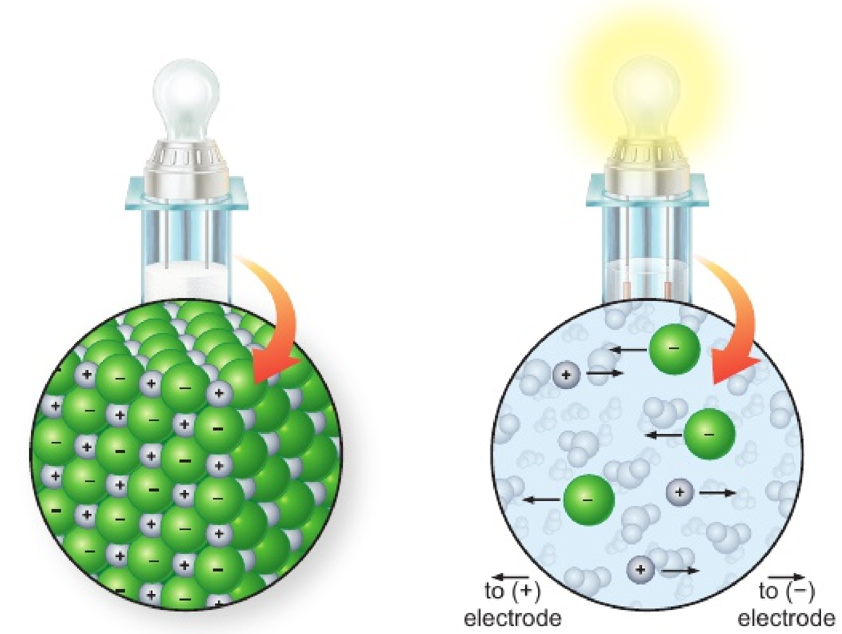
Ionic compounds conduct electricity when they are molten or dissolved in water. They do not conduct electricity when they are in the solid state.

Two conditions must be met for a substance to conduct electricity:

- it must contain charged particles
- these particles must be free to move.

7th **5** Samples of sodium chloride and magnesium oxide are both heated to 1080 °C. State and explain how the properties of these two compounds will or will not change at this temperature compared to room temperature.

When an ionic compound conducts electricity, it is the charged *ions* that carry the current. Ionic compounds do not conduct electricity in the solid state as the ions are not free to move from place to place. When the ionic compound is molten or in **aqueous solution**, the ions are free to move and so it does conduct electricity. Most ionic compounds are soluble in water and form an aqueous solution.



Positive and negative ions fixed in a solid do not conduct a current.

In solution, positive and negative ions move and conduct a current.

D Solid sodium chloride does not conduct electricity but aqueous sodium chloride does conduct.

The negative ions are also known as anions and they are attracted to the positive electrode, which is called the **anode**. The positive ions are also known as cations and they are attracted to the negative electrode, which is called the **cathode**.

It is important to remember that it is ions moving that enable ionic compounds to conduct electricity and that it is not *electrons* moving.

8th **6** Explain why ionic compounds conduct electricity when they are dissolved in water.

5th **7** Magnesium oxide is insoluble in water. State the condition needed for magnesium oxide to conduct electricity.

Exam-style question

Magnesium chloride is an ionic compound and has a high melting point. Explain why magnesium chloride has a high melting point. *(3 marks)*

Did you know?

Molten salts are used to store energy in some solar power stations. The salts are heated up by the Sun and release their thermal energy at night, allowing electricity to be generated when it is dark.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 You are given a substance and asked to find out if it is an ionic compound. Describe the tests you would carry out in order to decide.

Extend

E1 Table E shows some properties of five compounds.

Compound	Melting point (°C)	Soluble in water?	Conducts when molten?
A	2072	no	yes
B	191	no	no
C	782	yes	yes
D	605	yes	yes
E	150	yes	no

E

Identify the compounds that have ionic bonding and explain your reasoning. Give reasons why the other compounds do not have ionic bonding.

CC6a Covalent bonds

Specification reference: C1.28; C1.29; C.1.30; C1.31

Progression questions

- What are the names of some covalent molecules?
- How are covalent bonds formed?
- How can dot and cross diagrams be used to explain the formation of covalent molecules?

Did you know?

A cup of tea will contain over 1 000 000 000 000 000 000 000 000 (10^{24}) water molecules. This is the same as the estimated number of stars in the Universe.

5th **1** **a** What is a molecule?

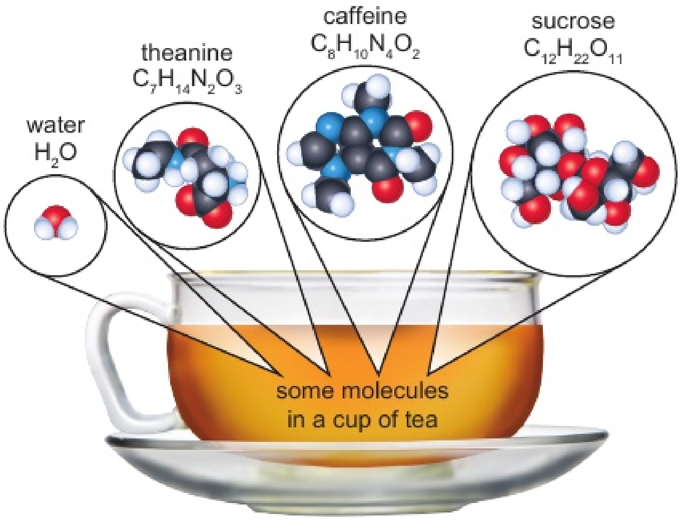
6th **b** What does a molecular formula tell you about a substance?

2 Oxygen molecules consist of two oxygen atoms.

6th **a** Write the molecular formula for oxygen.

7th **b** Explain why a noble gas, such as argon, exists as single atoms and not as molecules.

Molecular substances contain groups of atoms that are held together by strong bonds called **covalent bonds**. The number of atoms of each element bonded together in a simple **molecule** is shown by its **molecular formula.**

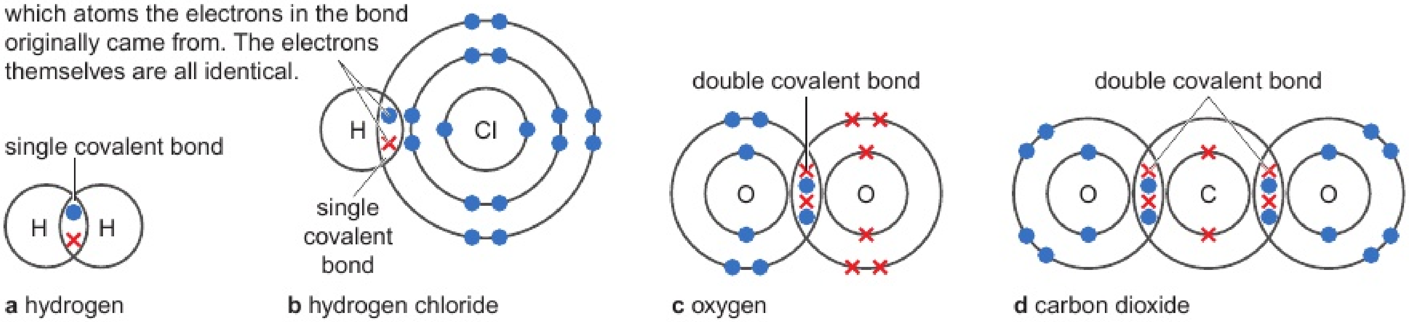


A Most of the molecules in a cup of tea are water, which has the molecular formula H_2O.

Covalent bonds are usually formed between non-metal atoms and are produced by sharing pairs of electrons. By forming the bond the atoms become more stable, because they can use the shared electrons to complete their **outer electron shells**. The reason why noble gases are so stable is because they have full outer electron shells.

The **dot and cross diagrams** in diagram B show how covalent bonds are formed. Counting the shared electrons, each atom now has a complete outer shell of electrons. Sometimes atoms share more than one pair of electrons to fill their outer shells. In oxygen and carbon dioxide the atoms share two pairs of electrons, to form **double bonds**.

Dots show electrons from one atom and crosses show electrons from the other atom. This allows us to see which atoms the electrons in the bond originally came from. The electrons themselves are all identical.



a hydrogen **b** hydrogen chloride **c** oxygen **d** carbon dioxide

B Dot and cross diagrams can be used to explain how covalent bonds are formed.

3 **a** Describe how covalent bonds are formed.

b Write the molecular formulae for the substances shown in diagram B.

4 The electronic configuration of fluorine is 2.7. Draw a dot and cross diagram to show how fluorine molecules (F_2) are formed.

The atoms in molecules are held together by strong **electrostatic forces** of attraction between the positive nuclei and the negative electrons in the bonded atoms. There are also some forces of attraction *between* molecules but these are very weak in comparison. Atoms and molecules are extremely small, about 10^{-10} metres across, so we represent them using models, such as those shown in Diagram C.

5 What holds the atoms together when a covalent bond has been formed?

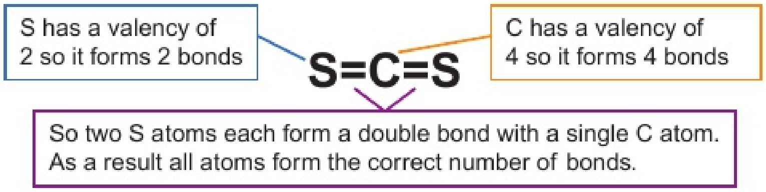
Working out molecular formulae

The numbers of covalent bonds formed by atoms of different elements are shown in table D. This is called the **valency** of the element. It is the same as the number of electrons needed to obtain a complete outer shell.

Group number	Examples	Outer electrons	Bonds formed	Valency
4	C and Si	4	4	4
5	N and P	5	3	3
6	O and S	6	2	2
7	F and Cl	7	1	1

D valencies of some elements

Diagram E shows how molecular formulae can be worked out by matching up the valencies, so that all atoms have the correct number of bonds (and so a complete outer electron shell).


S has a valency of 2 so it forms 2 bonds
S=C=S
C has a valency of 4 so it forms 4 bonds
So two S atoms each form a double bond with a single C atom. As a result all atoms form the correct number of bonds.

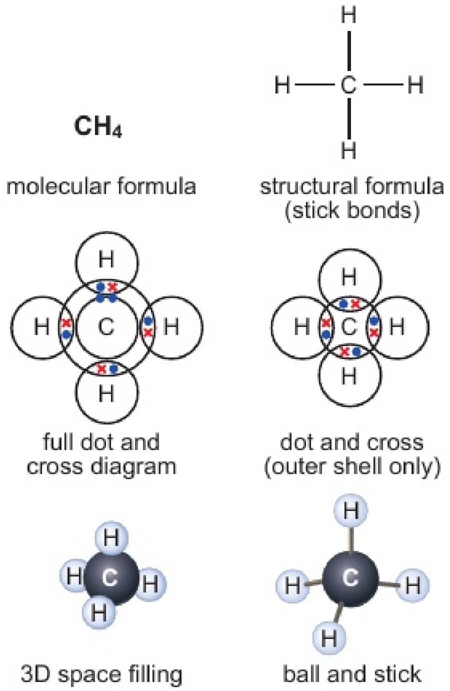
E working out the formula of carbon sulfide

7 Work out the molecular formulae for:

a oxygen fluoride **b** hydrogen sulfide **c** nitrogen chloride.

Exam-style question

Describe the bonding in a molecule of water, which contains two hydrogen atoms and one oxygen atom. *(3 marks)*


CH₄
molecular formula
H
H—C—H
H
structural formula (stick bonds)
H
H C H
H
full dot and cross diagram
H
H C H
H
dot and cross (outer shell only)
H
H C H
H
3D space filling
H
H C H
H
ball and stick

C different representations of methane

6 Look at diagram C.

a How are bonds represented in structural formulae?

b Describe the covalent bonds in methane.

c Draw four different models of a water molecule, including one dot and cross diagram.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 What does diagram B tell you about hydrogen chloride?

Extend

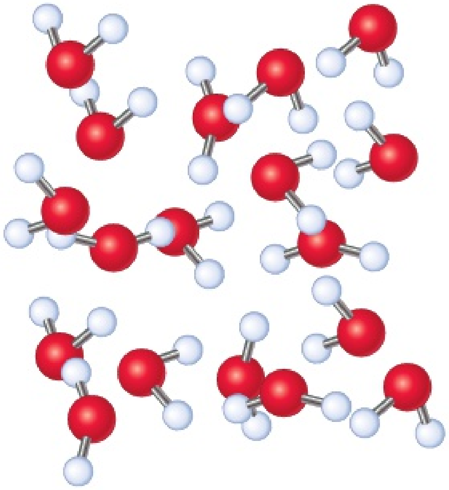
E1 Describe the bonding in a molecule of ammonia, which contains three hydrogen atoms and one nitrogen atom. Use diagrams in your answer.

CC7a Molecular compounds

Specification reference: C1.34; C1.39

Progression questions

- Why do simple molecular compounds have low boiling and melting points?
- Why are simple molecular compounds poor electrical conductors?
- What is a polymer?



A 'ball and stick' models of H_2O molecules

Did you know?

Intermolecular forces can allow water in an open container to be higher than the top of the container.

B

All **compounds** contain atoms of more than one **element**, chemically joined together by **bonds**. The properties of a compound are influenced by its atoms and by its type of bonding.

Some compounds exist as molecules – distinct groups of atoms joined by **covalent bonds**. They have **covalent, simple molecular structures**. An example is water. One molecule of water always contains one atom of oxygen covalently bonded to two atoms of hydrogen.

1 Look at diagram A.

a What do the red and white spheres represent?

b How are bonds represented in this model?

2 Why is the ratio of oxygen to hydrogen atoms the same in every glass of water?

Melting and boiling points

The covalent bonds in a water molecule are strong forces of attraction. However, there are also weak forces of attraction *between* molecules – **intermolecular forces**. These intermolecular forces hold water molecules together and must be overcome when turning liquid water into a gas. Small, simple molecules such as water often have low melting and boiling points, because it doesn't take much energy to overcome the weak intermolecular forces.

3 Covalent bonds are strong, so why does water have a low melting point?

4 What would you expect the strength of the bonds to be like between carbon and oxygen atoms in carbon dioxide, compared to the strength of the forces between neighbouring carbon dioxide molecules?

5 **a** Methane consists of molecules (containing one carbon atom covalently bonded to four hydrogen atoms). Would you expect methane to have a high or low melting point?

b Explain your reasoning.

Conduction of electricity

An electric current is a flow of charged particles. Simple molecules have no overall charge and so cannot carry an electric current. In a covalent bond, electrons are shared between two atoms. The strong forces between the negatively charged electrons and the positively charged nuclei hold the electrons in place. The electrons cannot flow and so cannot carry a current.

6 Explain why water is a poor conductor of electricity.

Polymers

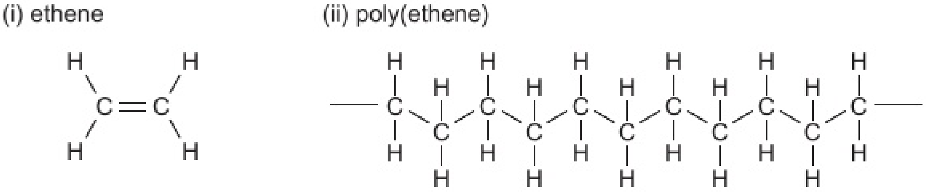
Monomers are small, simple molecules that can be joined in a chain to form a **polymer**. Carbon atoms can form up to four covalent bonds with other atoms, and so monomers are usually linked together by covalent bonds between carbon atoms. Most polymers contain a chain of carbon atoms.

7 What is a polymer?

Poly(ethene) (or 'polythene') is a common polymer made of ethene monomers (as shown in diagram D).

Polymer molecules can have different lengths. Longer polymers have more intermolecular forces between them. The longer chains also tend to get tangled up with one another. For these reasons, longer polymers have higher melting and boiling points than shorter ones.

C Poly(ethene) sheets are often used to protect things, such as plants. These are coffee beans being dried.



(i) ethene

(ii) poly(ethene)

D two dimensional models of: (i) an ethene molecule (monomer) (ii) a poly(ethene) molecule

8 **a** What monomer is used to make poly(butene)?

b What polymer is formed by linking styrene monomers together?

9 Explain why most polymers are solids at room temperature, whereas their monomers are liquids or gases.

Exam-style question

Explain why small molecules have a lower melting point than large polymer molecules. *(3 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 You can ask three questions to find out if a substance consists of simple molecules or not. What questions would you ask?

Extend

E1 Propene melts at −185 °C. Explain how the melting point and electrical conduction will change if other propene molecules are added together to form a chain.

CC7b Allotropes of carbon

Specification reference: C1.35; C1.36; C1.37; C1.38

Progression questions

- How are simple molecular structures different from giant covalent structures?
- What are the differences in structure between the different allotropes of carbon?
- How do we explain the properties and uses of graphite, diamond and fullerenes?

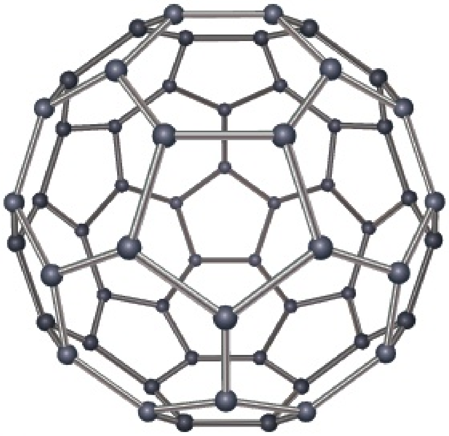
Molecules are groups of atoms joined by covalent bonds. Molecules can be compounds (such as water, H_2O) or elements (such as oxygen, O_2).

The element carbon can form a number of different molecules. Different structural forms of the same element are called **allotropes**. The structure and bonding in different allotropes influences their properties and uses.

5th **1** What is an allotrope?

Fullerenes

Carbon can form simple molecules called **fullerenes**, in which each carbon atom is covalently bonded to three other carbon atoms. Fullerenes are often tubular molecules (nanotubes) or spherical. An example is buckminsterfullerene (or 'bucky ball'), which has 60 carbon atoms that form a ball with the formula C_{60}.



A Buckminsterfullerene is a simple molecule.

6th **2** A fullerene has the formula C_{60}. Describe its structure.

6th **3** Explain why fullerenes have low melting points.

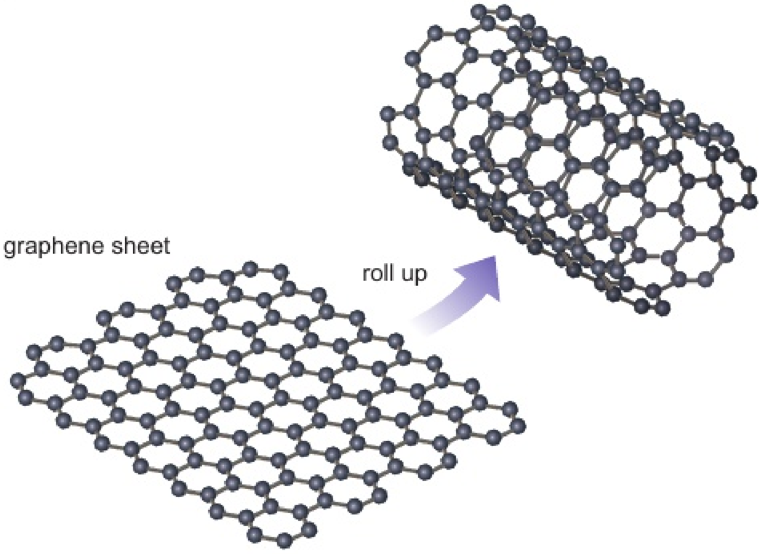
Fullerenes have weak intermolecular forces between the molecules and so have low melting points (or sublimation points). These weak forces also make them soft and slippery. However, the molecules themselves are very strong due to their covalent bonding.

Graphene

Graphene is similar to fullerenes but is not a simple molecule. It consists of a sheet of carbon atoms with no fixed formula. The sheet is just one atom thick, making it the lightest known material, but its covalent bonds make it extremely strong. It also allows free electrons to move across its surface and so is a good electrical conductor.

Did you know?

Buckminsterfullerene is named after an American architect called Richard Buckminster Fuller, who designed spherical buildings with a similar structure to C_{60}.



B Graphene can be a sheet or can be rolled into a tube.

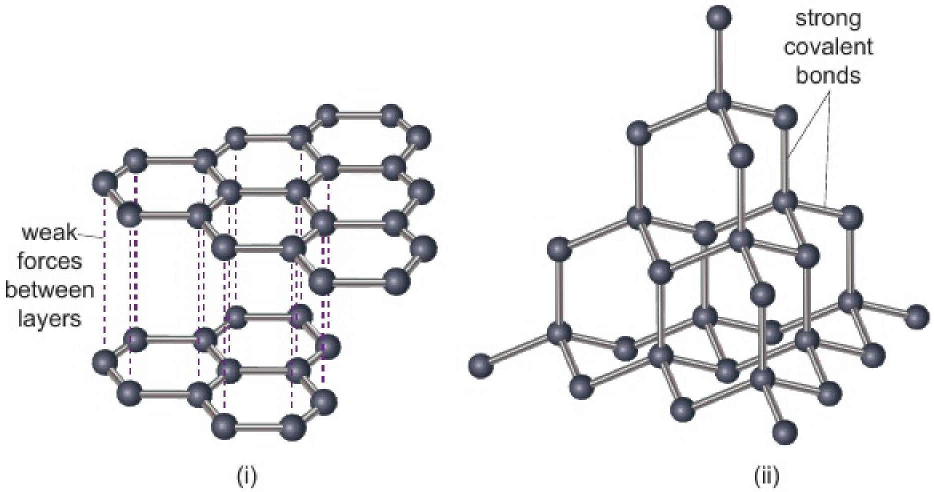
6th **4** Explain why graphene is not a simple molecule.

Giant structures of carbon

Diamond and graphite are two more allotropes of carbon that are not simple molecules. They are both examples of **covalent, giant molecular structures**, which have huge three-dimensional networks of carbon atoms linked by covalent bonds.

5 How many covalent bonds will most carbon atoms form in graphite, diamond and C_{60}?

6 Describe how simple molecular structures are different from giant molecular structures.



(i) (ii)

C small sections of (i) graphite and (ii) diamond to show the arrangements of atoms

Graphite and diamond both have high melting points because of the many strong covalent bonds that need to be broken to melt the solids.

However, graphite has three covalent bonds for each carbon atom, whereas diamond has four. This gives graphite a layered structure and means that not all of its electrons are held in covalent bonds. These **delocalised electrons** are free to move and can carry an electrical current. Since graphite conducts electricity well and is cheap and not very reactive, it is used as electrodes (in electrolysis).

7 Explain why graphite conducts electricity but diamond does not.

The sheets of carbon atoms in graphite are held together by weak forces of attraction (purple dashed lines in diagram C). These weak forces allow the layers to slide past each other, which makes graphite quite soft and useful as a **lubricant**.

Diamond is very hard because it has a rigid network of carbon atoms in a tetrahedral arrangement, joined by strong covalent bonds. This property makes diamond useful for tools to cut things. It is also an electrical insulator because it has no free charged particles.

8 Explain why:

a graphite is used as electrodes

b diamonds are used on cutting heads when drilling through rocks

c spherical fullerenes are used in some lubricants.

D This cutting head, used in mining, is studded with diamonds.

Exam-style question

Explain why graphite is softer than diamond. *(4 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe how the structures of four allotropes of carbon cause their properties.

Extend

E1 Graphene sheets can be rolled into tubes. Predict the properties of these tubes.

CC7c Properties of metals

Specification reference: C1.40; C1.42

Progression questions

- What are the typical physical properties of metals and non-metals?
- How are the particles arranged in metals?
- How can we explain the properties of a metal in terms of its bonding and structure?

The bucket is made of iron. Metals have some common properties:

- solids with high melting points
- shiny (when polished)
- malleable
- high density
- good conductors of electricity.

Sulfur is a non-metal. Non-metals have some common properties:

- solids, liquids or gases with low melting points
- not usually shiny (when solid)
- brittle (when solid)
- low density
- poor conductors of electricity.

A Sulfur being unloaded at a port in Darwin, Australia.

Chemists classify elements into **metals** and **non-metals**, depending on their properties. Just over three-quarters of the elements are metals.

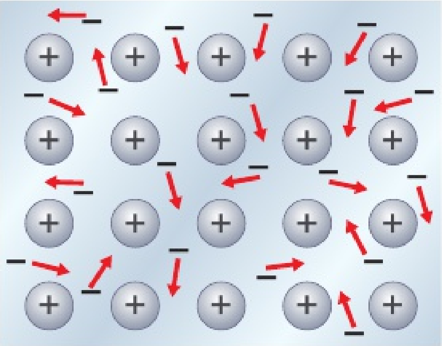
A metal or a non-metal may not have all the common properties shown in photo A.

1 Give two general properties of:
  a metals
  b non-metals.

2 Name a form of the non-metal carbon that is a good conductor of electricity.

Metallic structure and bonding

The atoms in a metallic element are all the same size and are packed closely together in layers to form a giant **lattice**.



B Metals consist of stacked layers of ions in a 'sea' of delocalised ('free') electrons.

Metal atoms have one, two or three electrons in their outer shell. These outer shell electrons are lost from each atom and become free to move randomly throughout the metal. This leaves a giant lattice of positive metal ions surrounded by a 'sea' of delocalised electrons, which move randomly in all directions.

Metallic bonding is the electrostatic attraction between the positive metal ions and the negative delocalised electrons. This attraction is strong, so metals have high melting and boiling points.

3 **a** Describe the structure of a metal.
  b Describe the bonding in a metal.

4 Explain why most metals have high melting points.

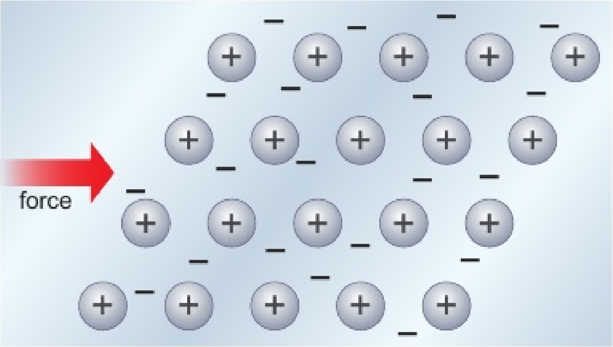
Did you know?

Osmium is the most dense metal at room temperature (the mass of 1 cm^3 is 22.6 g). A lump of osmium the size of an average smartphone has a mass of 1.5 kg (the same as one and a half bags of sugar)!

Metals are malleable

Metals are **malleable**. This means that they can be hammered or rolled into shape without shattering. When you hit a metal, the layers of ions slide over each other. The 'sea' of electrons holds the ions together and so the metal changes shape instead of breaking.

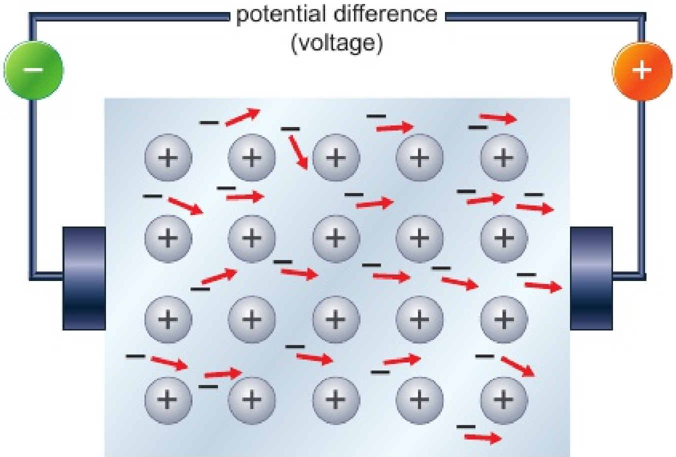
7th **5** Copper is used to make some saucepans. Explain why copper can be bent and shaped into a saucepan.



C When hit or bent, the layers of ions in a metal can slide over each other.

Metals conduct electricity

The delocalised electrons move randomly between the positive metal ions in all directions. When a potential difference (voltage) is applied between two points on a piece of metal, the electrons will flow towards the positive side. This flow of electrons transfers energy and forms an electrical current.



E When a voltage is applied to a piece of metal, an electrical current flows.

7th **6** Copper is used to make electrical wires. Explain why copper is a good conductor of electricity.

Substances that conduct electricity better than others have a higher **electrical conductivity**. The electrical conductivity of the metals increases as the number of delocalised electrons increases. Each sodium ion has one positive charge, Na^+, and contributes 1 electron to the 'sea' of delocalised electrons. Each magnesium ion has two positive charges, Mg^{2+}, and contributes 2 electrons to the 'sea' of delocalised electrons, and so magnesium has a higher electrical conductivity than sodium.

8th **7** Aluminium forms Al^{3+} ions. Explain why aluminium has a higher electrical conductivity than magnesium.

Exam-style question

Explain how metals conduct electricity. *(2 marks)*

D Copper conducts electricity well and so is used for electrical wiring.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 You are given a solid substance and asked to find out if it is a metal or a non-metal. Describe the properties you would need to find out about.

Extend

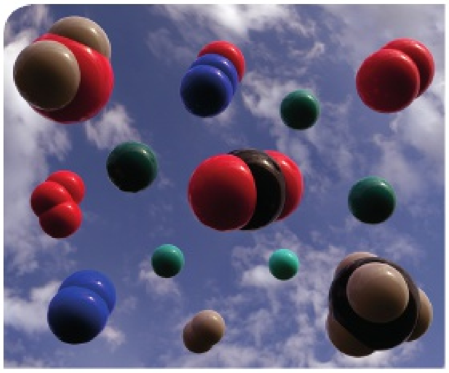
E1 Elements A and B are solids at room temperature. Element A has a melting point of 98 °C, a density of 0.97 g/cm^3 and conducts electricity. Element B has a melting point of 217 °C, a density of 4.81 g/cm^3 and doesn't conduct electricity. Are these elements metals or non-metals? Explain your reasoning.

CC7d Bonding models

Specification reference: C1.32; C1.41

Progression questions

- What different types of structure and bonding models are used to describe substances?
- How do these models help explain the properties of substances?
- What are the limitations of the models that we use to show structure and bonding?



A 3D models of some gas molecules

1 Look at the substances in the box below.

potassium fluoride
carbon dioxide
diamond
magnesium

Which substance:

5th **a** conducts electricity when solid

6th **b** is most likely to dissolve in water

6th **c** has the lowest melting point?

6th **2** **a** Name the type of bonding and structure that usually has a low melting point.

7th **b** Explain why the melting points of these substances are usually low.

Scientists have developed models to explain how different types of bonds and structures are formed. These models help us explain the properties of different substances. Most elements and compounds fit into one of the four main models summarised below.

Ionic

Where found: in most compounds containing metal and non-metal atoms.

Bonding: ionic bonds formed by the loss and gain of electrons to produce oppositely charged ions that attract one another.

Structure: billions of ions held together in a lattice structure.

Properties:

- high melting/boiling points
- many are soluble in water
- conduct electricity when liquid or in solution but do not when solid.

Simple molecular (covalent)

Where found: in most non-metal elements and compounds.

Bonding: covalent bonds formed when atoms share pairs of electrons.

Structure: small, distinct groups of atoms.

Properties:

- low melting/boiling points
- a few are soluble in water
- most do not conduct electricity.

Giant covalent

Where found: in a few non-metal elements and some compounds of non-metals.

Bonding: covalent bonds formed when atoms share pairs of electrons.

Structure: billions of atoms held together in a lattice structure.

Properties:

- high melting/boiling points
- insoluble in water
- most do not conduct electricity (except in carbon as graphite).

Metallic

Where found: in all metals.

Bonding: metallic bonds are the electrostatic attraction between positive metal ions and negative delocalised electrons.

Structure: billions of ions held together in a giant lattice structure of positive ions in a 'sea' of negative delocalised electrons.

Properties:

- high melting/boiling points
- insoluble in water
- conduct electricity when solid or liquid.

The models help to explain some of the properties. For example:

- Substances with high melting points have many strong bonds that need to be broken during melting. Substances with low melting points have only weak forces that need to be overcome between molecules.
- Substances that conduct electricity have charged particles that can freely move. Substances that do not conduct electricity have charged particles that cannot move or particles that are not charged.

3 Explain why sodium metal conducts electricity when it is solid or liquid but sodium chloride conducts only when liquid.

4 A white solid with a melting point of 2614 °C does not dissolve in water.

a Is the substance ionic or covalent or can you not tell? Explain your answer.

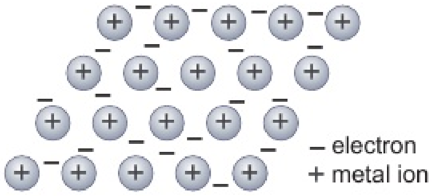
b Describe a test you could do to help you answer part a.

5 What do sodium ions and chloride ions have in common?

Problems with bonding models

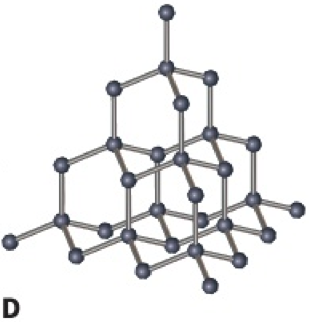
The bonding models that we use to explain the properties of matter all have certain weaknesses or limitations.

- The dot and cross diagram for hydrogen chloride in diagram B shows how electrons are shared in covalent bonds. However, dot and cross diagrams do not show the structure formed and they suggest that the electrons in different atoms are different, when they are actually all the same.
- The metallic model in diagram C shows the metal ions held in a lattice and explains why it conducts electricity, but the model does not show that the ions will be vibrating all the time.



C

- 3D ball and stick models, like diagram D for diamond, show which atoms are joined together and show the shape of the structure. However, they also show the atoms too far apart and there are not really 'sticks' holding the atoms together.



D

6 **a** Draw a 3D structural ball and stick model of a sodium chloride lattice.

b Draw a dot and cross diagram for sodium chloride.

c Explain one strength and one weakness of a dot and cross diagram for sodium chloride.

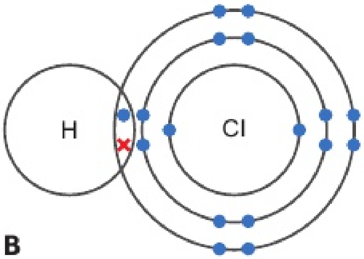
7 Describe one strength and one weakness of the 3D models shown in photo A.

Exam-style question

Suggest why the melting point of silicon dioxide (1610 °C) is so much higher than the temperature at which solid carbon dioxide changes state (−78.5 °C), although both compounds contain covalent bonds. *(3 marks)*

Did you know?

Ideas about chemical bonds can be traced back to Roman times. The Roman poet Lucretius (*c.*95 BCE–*c.*55 BCE) imagined atoms as tiny spheres with fishhooks embedded in them. The atoms formed bonds when the fishhooks got tangled up with one another.



B

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

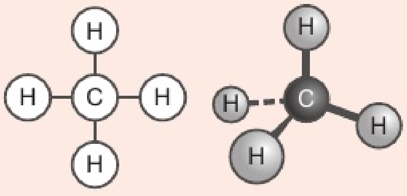
S1 Draw up a summary table describing the four 'types of bonding and structure' under the headings: 'where it occurs'; 'how bonds form'; 'type of structure'; 'properties' and 'examples'.

Extend

E1 The models below show methane.

a Draw a dot and cross diagram for methane.

b Describe one strength and one weakness of your dot and cross diagram and the two models below.



E

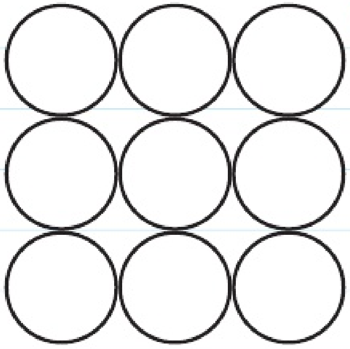
Bonding in compounds

Sodium chloride and hydrogen chloride are both compounds of chlorine. Sodium chloride has a boiling point of 1413 °C. Hydrogen chloride has a boiling point of −85 °C.

Explain this difference in boiling points in terms of the structure and bonding in the particles of the two compounds. (6 marks)

Student answer

As it is a metal and a non-metal, sodium chloride contains ionic bonds with lots of oppositely charged ions attracting each other to form a giant lattice structure [1]. *Ionic compounds contain lots of strong bonds which keep it solid* [2].



[3]

Hydrogen chloride contains covalent bonds and is made up of molecules. The covalent bonds are strong bonds that hold the atoms together in the molecules. Substances which contain molecules have low boiling points [4].

[1] This is a good description of the bonding and structure of sodium chloride.

[2] The question asked for an explanation of the high boiling point, not why it was solid.

[3] The diagram will get no credit as it is not labelled or described.

[4] This part of the answer does not explain why hydrogen chloride has a low boiling point.

Verdict

This is an acceptable answer. It contains a good description of the bonding and structures of sodium chloride and hydrogen chloride. The answer has included information on both of the compounds in the question and uses correct scientific terminology.

This answer could be improved by explaining why the boiling points are low or high. The student should use scientific knowledge to explain the link between the structures of the compounds, the bonding within them and their boiling points.

Exam tip

You are more likely to get better marks in a question which requires extended writing if you plan your answer before you start. The plan can simply be a list of the keywords or phrases that you want to include. It is also useful to organise these keywords in a logical order to help structure your answer.

Paper 5

CP1 Motion

Penguins cannot climb. They get onto the ice by accelerating to a high speed under the water. As they move upwards out of the water, gravity pulls on them and they slow down. But if they are swimming fast enough they land on the ice before they stop moving.

In this unit you will learn about quantities that have directions (such as forces). You will find out how to calculate speeds and accelerations, and how to represent changes in distance moved and speed on graphs.

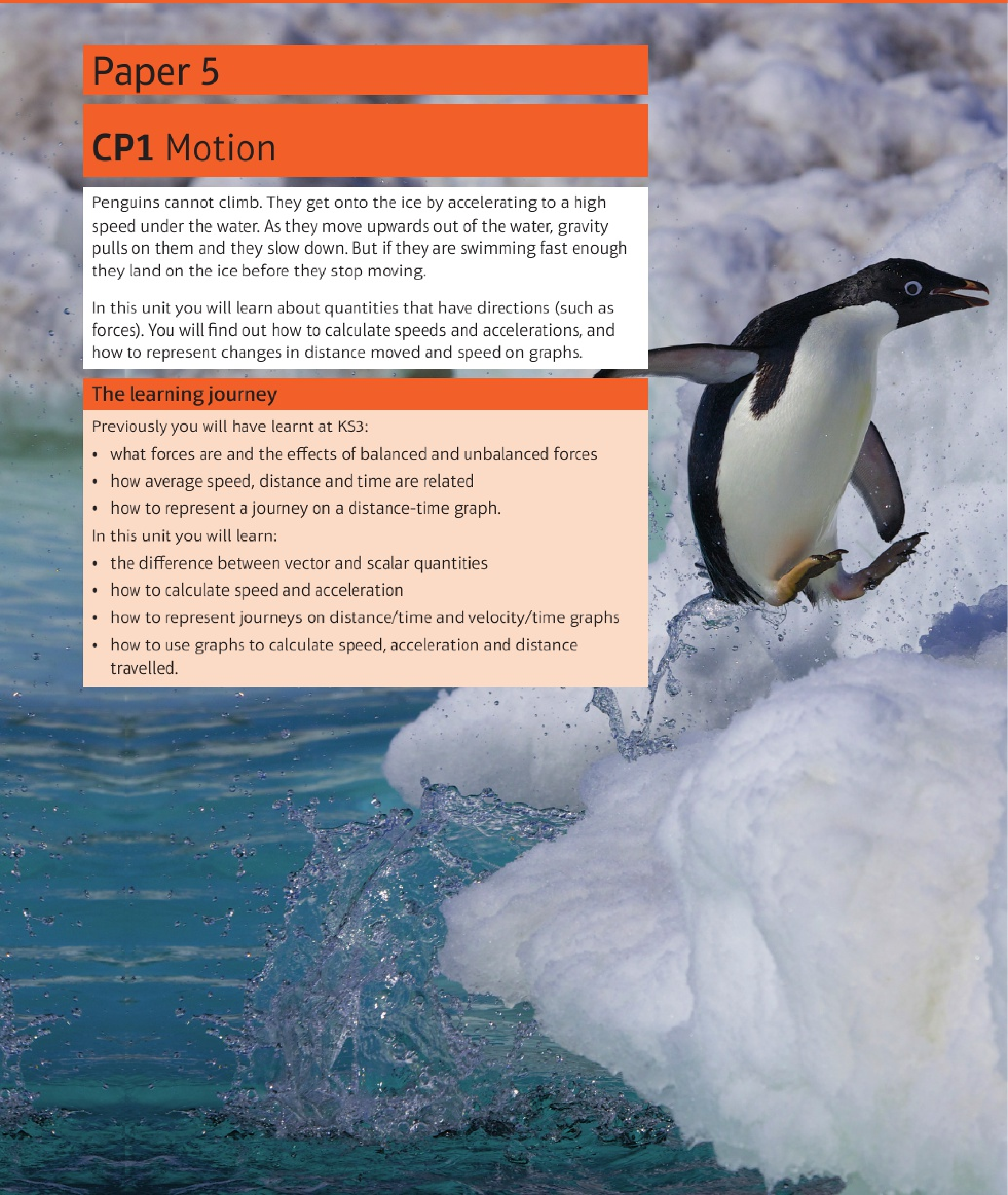
The learning journey

Previously you will have learnt at KS3:

- what forces are and the effects of balanced and unbalanced forces
- how average speed, distance and time are related
- how to represent a journey on a distance-time graph.

In this unit you will learn:

- the difference between vector and scalar quantities
- how to calculate speed and acceleration
- how to represent journeys on distance/time and velocity/time graphs
- how to use graphs to calculate speed, acceleration and distance travelled.



CP1a Vectors and scalars

Specification reference: P2.1; P2.2; P2.3; P2.4; P2.5

Progression questions

- What are vector and scalar quantities?
- What are some examples of scalar quantities and their corresponding vector quantities?
- What is the connection between the speed, velocity and acceleration of an object?

A The person in the air stays there because of the force provided by the jets of water.

7th **1** Upthrust is a force that helps objects float. Sketch one of the boats in photo A and add arrows to show two forces on the boat acting in a vertical direction.

5th **2** Describe the differences between mass and weight.

7th **3** Explain why we say that displacement is a vector quantity.

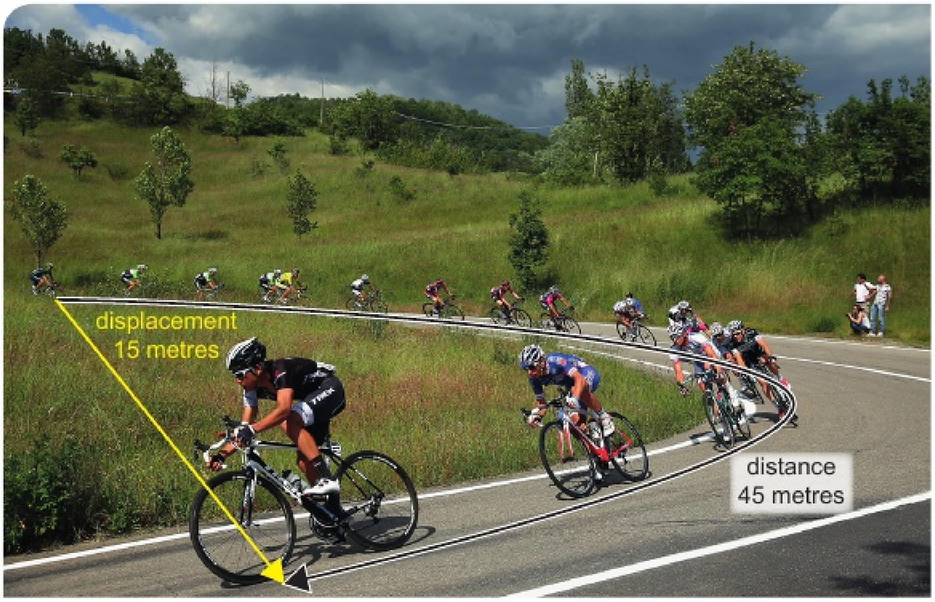
7th **4** Runners in a 400 m race complete one circuit of an athletics track. What is their displacement at the end of the race?

The **force** needed to keep the person in photo A in the air depends on his **weight**. Weight is a force that acts towards the centre of the Earth. All forces have both a **magnitude** (size) and a direction, and are measured in newtons (N).

Quantities that have both size and direction are **vector quantities**. So forces are vectors. Forces are often shown on diagrams using arrows, with longer arrows representing larger forces.

The weight of the person in photo A depends on his **mass**. Mass measures the amount of matter in something and does not have a direction. Quantities that do not have a direction are called **scalar quantities**. Other scalar quantities include **distance**, **speed**, energy and time.

Displacement is the distance covered in a straight line, and has a direction. The displacement at the end of a journey is usually less than the distance travelled because of the turns or bends in the journey.



B The bend in the road means that the distance the cyclists cover is greater than their final displacement.

The speed of an object tells you how far it moves in a certain time. **Velocity** is speed in a particular direction. For example a car may have a velocity of 20 m/s northwards.

D These skaters maintain a constant speed around the bend, but their velocity is changing.

Other vector quantities include:

- **acceleration** – a measure of how fast velocity is changing
- **momentum** – a combination of mass and velocity.

Exam-style question

Weight and upthrust are both vector quantities.

a Name one other vector quantity that is not a force. *(1 mark)*

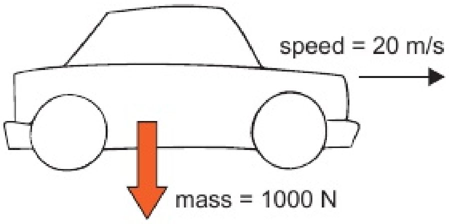
b Explain why you do not need to state a direction when describing a weight. *(1 mark)*

Did you know?

Cyclists can achieve speeds of up to 70 mph (that's over 100 km/h and approximately 30 m/s).

5 Look at photo B. Explain why the cyclists' velocity will change even if they maintain the same speed.

6 A student draws the diagram below. Explain what is wrong with it.



C

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Sally walks 1 km from her home to school. When she arrives, she tells her science teacher 'My velocity to school this morning was 15 minutes'. What would her teacher say?

S2 Explain the difference between displacement and distance, and between speed and velocity. Give an example of each.

Extend

E1 A car is going around a roundabout. Explain why it is accelerating even if it is moving at a constant speed.

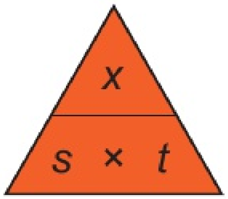
CP1b Distance/time graphs

Specification reference: P2.6; P2.7; P2.11; P2.12

Progression questions

- How do you use the equation relating average speed, distance and time?
- In metres per second, what are the typical speeds that someone might move at during the course of a day?
- How do you represent journeys on a distance/time graph?

A *ThrustSSC* broke the land speed record in 1997 at a speed of 1228 km/h (341 m/s). This was faster than the speed of sound (which is approximately 330 m/s).



B This equation triangle can help you to rearrange the equation for speed (*s*), where *x* is used to represent distance and *t* represents time. Cover up the quantity you want to calculate and write what you see on the right of the = sign.

Worked example W1

How far would *ThrustSSC* have travelled in 5 seconds during its record-breaking run?

distance = average speed × time
= 341 m/s × 5 s
= 1705 m

1 A car travels 3000 m in 2 minutes (120 seconds). Calculate its speed in m/s.

2 Look at diagram C. How far does a high speed train travel in 10 minutes?

The speed of an object tells you how quickly it travels a certain distance. Common units for speed are metres per second (m/s), kilometres per hour (km/h) and miles per hour (mph).

The speed during a journey can change, and the **average speed** is worked out from the total distance travelled and the total time taken. The **instantaneous speed** is the speed at a particular point in a journey.

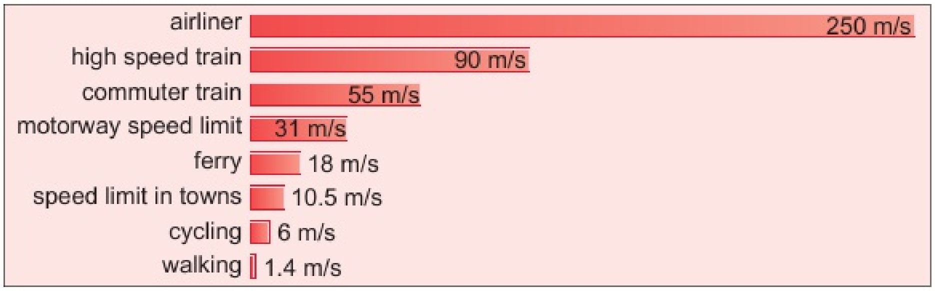
Speed can be calculated using the following equation:

$$\text{(average) speed (m/s)} = \frac{\text{distance (m)}}{\text{time taken (s)}}$$

The equation can be rearranged to calculate the distance travelled from the speed and the time.

$$\underset{\text{(m)}}{\text{distance travelled}} = \underset{\text{(m/s)}}{\text{average speed}} \times \underset{\text{(s)}}{\text{time}}$$

To measure speed in the laboratory you need to measure a distance and a time. For fast-moving objects, using **light gates** to measure time will be more accurate than using a stopwatch.

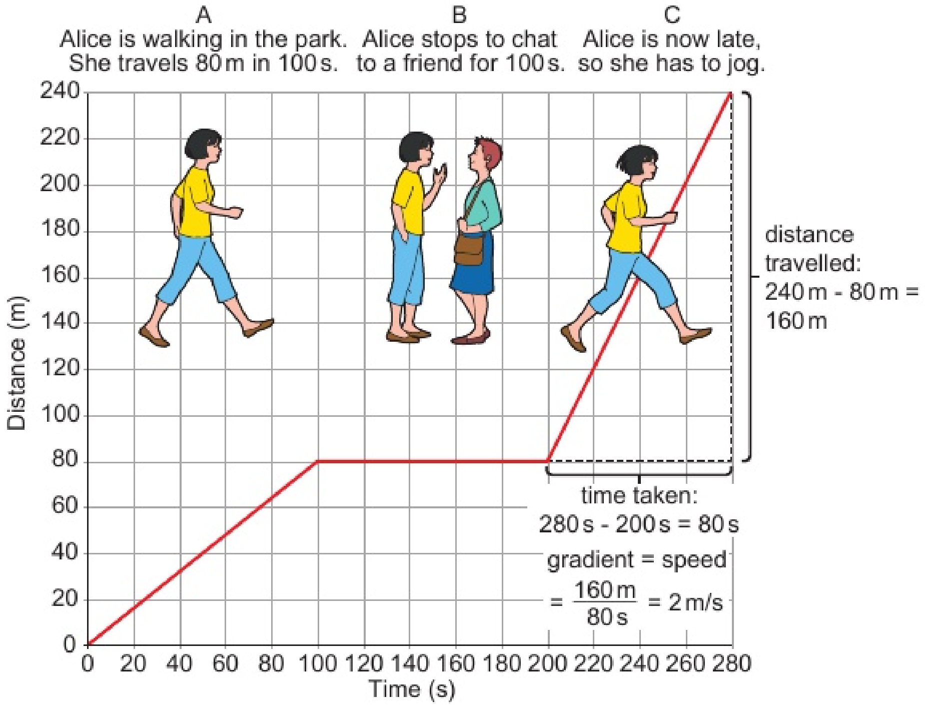


C some typical speeds

Distance/time graphs

A journey can be represented on a **distance/time graph**. Since time and distance are used to calculate speed, the graph can tell us various things about speed:

- horizontal lines mean the object is stationary (its distance from the starting point is not changing)
- straight, sloping lines mean the object is travelling at constant speed
- the steeper the line, the faster the object is travelling
- the speed is calculated from the **gradient** of the line.



D The gradient of a distance/time graph gives the speed.

Worked example W2

In graph D, what is Alice's speed for part C of her walk?

$$\text{gradient} = \frac{\text{vertical difference between two points on a graph}}{\text{horizontal difference between the same two points}}$$

$$= \frac{240\text{ m} - 80\text{ m}}{280\text{ s} - 200\text{ s}}$$

Make sure you take the starting value away from the end value each time.

$$\text{speed} = \frac{160\text{ m}}{80\text{ s}}$$

$$\text{speed} = 2\text{ m/s}$$

Exam-style question

A snail travels 300 cm in 4 minutes. Calculate the speed of the snail in m/s. *(3 marks)*

Did you know?

The fastest wind speed recorded was 113 m/s, in Australia in 1996. There may be higher wind speeds than this inside tornados, but they have never been recorded. A gale force wind blows at around 20 m/s.

3 Look at graph D. Calculate Alice's speed for:

a part A on the graph

b part B on the graph.

4 If Alice had not stopped to chat but had walked at her initial speed for 280 s, how far would she have travelled?

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 A peregrine falcon flies at 50 m/s for 7 seconds. How far does it fly?

S2 Zahir starts a race fast, then gets a stitch and has to stop. When he starts running again he goes more slowly than before. Sketch a distance/time graph to show Zahir's race if he runs at a constant speed in each section of the race.

Extend

E1 Look at question S2. Zahir's speeds are 3 m/s for 60 seconds, 2 m/s for 90 seconds and his rest lasted for 30 seconds. Plot a distance/time graph on graph paper to show his race.

CP1c Acceleration

Specification reference: P2.8; P2.9; P2.13

Progression questions

- How do you calculate accelerations from a change in velocity and a time?
- How are acceleration, initial velocity, final velocity and distance related?
- What is the acceleration of free fall?

A A fighter plane can accelerate from 0 to 80 m/s (180 mph) in 2 seconds.

Fighter planes taking off from aircraft carriers use a catapult to help them to accelerate to flying speed.

A change in velocity is called acceleration. Acceleration is a vector quantity – it has a size (magnitude) and a direction. If a moving object changes its velocity or direction, then it is accelerating.

The acceleration tells you the change in velocity each second, so the units of acceleration are metres per second per second. This is written as m/s^2 (metres per second squared). An acceleration of $10\ m/s^2$ means that each second the velocity increases by 10 m/s.

Acceleration is calculated using the following equation:

$$\text{acceleration } (m/s^2) = \frac{\text{change in velocity } (m/s)}{\text{time taken } (s)}$$

This can also be written as:

$$a = \frac{v - u}{t}$$

where a is the acceleration

v is the final velocity

u is the initial velocity

t is the time taken for the change in velocity.

Worked example W1

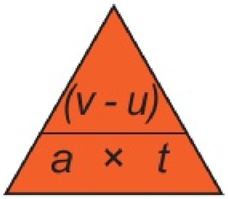
An airliner's velocity changes from 0 m/s to 60 m/s in 20 seconds. What is its acceleration?

$$a = \frac{v - u}{t}$$

$$= \frac{60\ m/s - 0\ m/s}{20\ s}$$

$$= 3\ m/s^2$$

1 How are velocity and acceleration connected?



B This triangle can help you to rearrange the equation.

2 Calculate the take-off acceleration of the fighter plane in photo A.

Acceleration does not always mean getting faster. An acceleration can also cause an object to get slower. This is sometimes called a **deceleration**, and the acceleration will have a negative value.

8th **3** A car slows down from 25 m/s to 10 m/s in 5 seconds. Calculate its acceleration.

Acceleration can be related to initial velocity, final velocity and distance travelled by this equation:

$$(\text{final velocity})^2 - (\text{initial velocity})^2 = 2 \times \text{acceleration} \times \text{distance}$$
$$(\text{m/s})^2 \qquad (\text{m/s})^2 \qquad (\text{m/s}^2) \qquad (\text{m})$$

This can also be written as $v^2 - u^2 = 2 \times a \times x$, where x represents distance.

Worked example W2

A car travelling at 15 m/s accelerates at 1.5 m/s^2 over a distance of 50 m. Calculate its final velocity.

$v^2 = (2 \times a \times x) + u^2$

$= (2 \times 1.5\ \text{m/s}^2 \times 50\ \text{m}) + (15\ \text{m/s} \times 15\ \text{m/s})$

$v^2 = 375\ (\text{m/s})^2$

$v = \sqrt{375}\ (\text{m/s})^2$

$= 19.4\ \text{m/s}$

8th **4** A cyclist accelerates from 2 m/s to 8 m/s with an acceleration of 1.5 m/s^2. How far did she travel while she was accelerating? Use the equation $x = \dfrac{v^2 - u^2}{2 \times a}$.

Acceleration due to gravity

An object in free fall is moving downwards because of the force of gravity acting on it. If there are no other forces (such as air resistance), the acceleration due to gravity is 9.8 m/s^2. This is represented by the symbol g, and is often rounded to 10 m/s^2 in calculations.

5 Look at photo C.

8th **a** Calculate the acceleration on the ejecting pilot in m/s^2.

8th **b** How does this compare to everyday accelerations?

Exam-style question

A cheetah accelerates from rest to 30 m/s in 3 seconds. Calculate the acceleration of the cheetah. *(2 marks)*

Did you know?

Large accelerations are often compared to the acceleration due to gravity (g). The ejector seat in this aircraft can subject the pilot to accelerations of up to 12g or more.

C

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Explain how positive, negative and zero accelerations change the velocity of a moving object.

S2 A car travelling at 40 m/s comes to a halt in 8 seconds. What is the car's acceleration and how far does it travel while it is stopping?

Extend

E1 A train is travelling at 35 m/s. It slows down with an acceleration of –0.5 m/s^2. How much time does it take to stop and how far does it travel while it is stopping?

CP1d Velocity/time graphs

Specification reference: P2.10

Progression questions

- How do you compare accelerations on a velocity/time graph?
- How can you calculate acceleration from a velocity/time graph?
- How can you use a velocity/time graph to work out the total distance travelled?

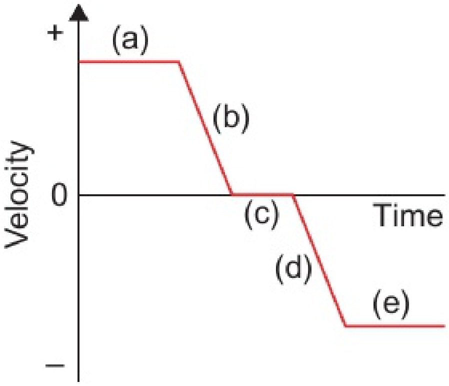
A Top Fuel dragsters can reach velocities of 150 m/s (335 mph) in only 4 seconds.

In a drag race, cars accelerate in a straight line over a short course of only a few hundred metres.

The changing velocity of a dragster during a race can be shown using a **velocity/time graph**.

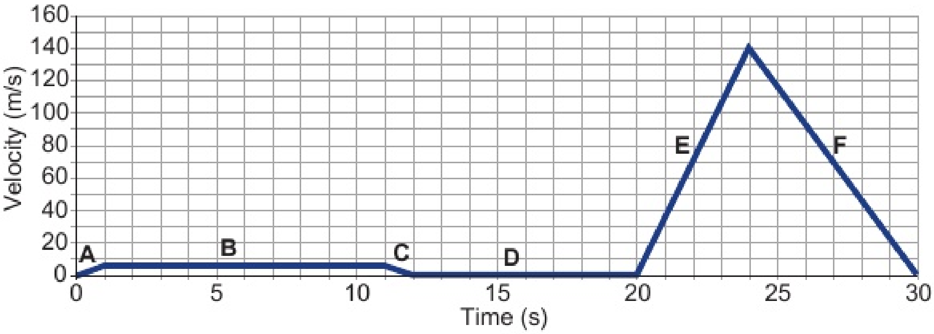
On a velocity/time graph:

- a horizontal line means the object is travelling at constant velocity
- a sloping line shows that the object is accelerating. The steeper the line, the greater the acceleration. If the line slopes down to the right, the object is decelerating (slowing down). You can find the acceleration of an object from the gradient of the line on a velocity/time graph.
- a negative velocity (a line below the horizontal axis) shows the object moving in the opposite direction.



B The graph shows a lift moving up at a constant speed (a), slowing to a stop (b) and waiting at a floor (c) then accelerating downwards (d) and then travelling downwards at a constant speed (e).

Graph C is a simplified velocity/time graph for a dragster. It shows the car driving slowly to the start line, waiting for the signal, and then racing.



C simplified velocity/time graph for a drag race

1 What does a horizontal line on a velocity/time graph tell you about an object's velocity?

2 **a** In which part of graph C is the dragster travelling at a constant velocity?

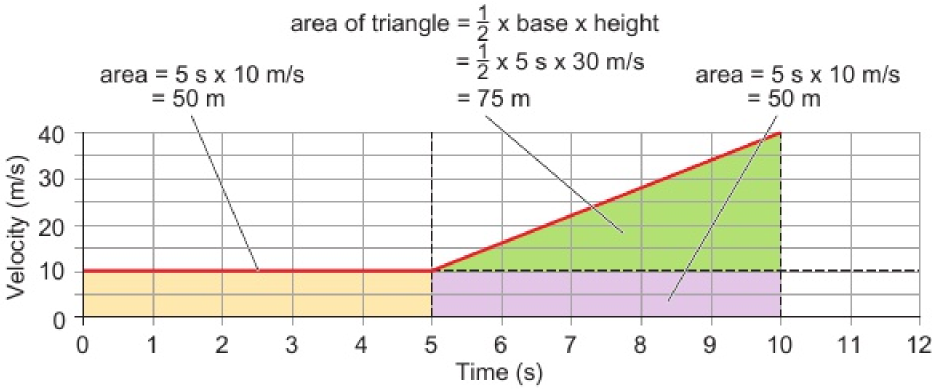
b In which part of the graph does the dragster have its greatest acceleration?

c Which part(s) of the graph show that the dragster is slowing down?

3 Look at graph C. Calculate the acceleration during part F of the journey.

Calculating distance travelled from a graph

The area under a velocity/time graph is the distance the object has travelled (distance is calculated by multiplying a velocity and a time). In graph D, the distance travelled in the first 5 seconds is the area of a rectangle. The distance travelled in the next 5 seconds is found by splitting the shape into a triangle and a rectangle, and finding their areas separately.



D

The total distance travelled by the object in graph D is the sum of all the areas.

total distance travelled = 50 m + 50 m + 75 m = 175 m

4 Look at graph C. The dragster travels at 5 m/s as it approaches the start line.

a How far does it travel to get to the start line?

b What is the distance travelled by the dragster during the race and slowing down afterwards?

5 Mel draws a graph showing a bus journey through town. Explain why this should be called a speed/time graph, not a velocity/time graph.

Exam-style question

Explain why the area under part of a velocity/time graph gives you the distance covered. *(3 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Table E below gives some data for a train journey. Draw a velocity/time graph from this and join the points with straight lines. Label your graph with all the things you can tell from it. Show your working for any calculations you do.

Time (s)	Velocity (m/s)
0	0
20	10
30	30
60	30
120	0

E

Extend

E1 In a fitness test, students run up and down the sports hall. They have to run faster after each time they turn around. Sketch a velocity/time graph for 4 lengths of the hall, if each length is run at a constant speed.

Vectors and scalars

Explain the statements below, giving examples in each case.

- The speed of an object has the same value as its velocity.
- The displacement of an object from its starting point is often not the same as the distance travelled.
- The displacement of an object at the end of a journey can never be greater than the distance travelled. (6 marks)

Student answer

Speed is a scalar and velocity is a vector because it has a direction. So if a car goes around a corner at a constant speed, the magnitude [1] of the velocity does not change but the velocity is changing because the direction is changing [2].

Displacement is a vector, and is the distance in a straight line between the starting point and finishing point. Displacement has a direction [3]. Distance is a scalar, and is the actual distance moved during a journey including all the twists and turns [4].

[1] This is a good use of correct scientific terminology.

[2] This is a good explanation of the first statement, and includes an example.

[3] This is a good description of the meaning of displacement.

[4] Although the student has described distance, there isn't an example that illustrates the difference.

Verdict

This is an acceptable answer. It shows a good understanding of the differences between vectors and scalars. The answer also provides good descriptions of the terms speed, velocity, distance and displacement. The use of scientific language is good and the answer is arranged logically. However, there are some parts of the answer which are missing.

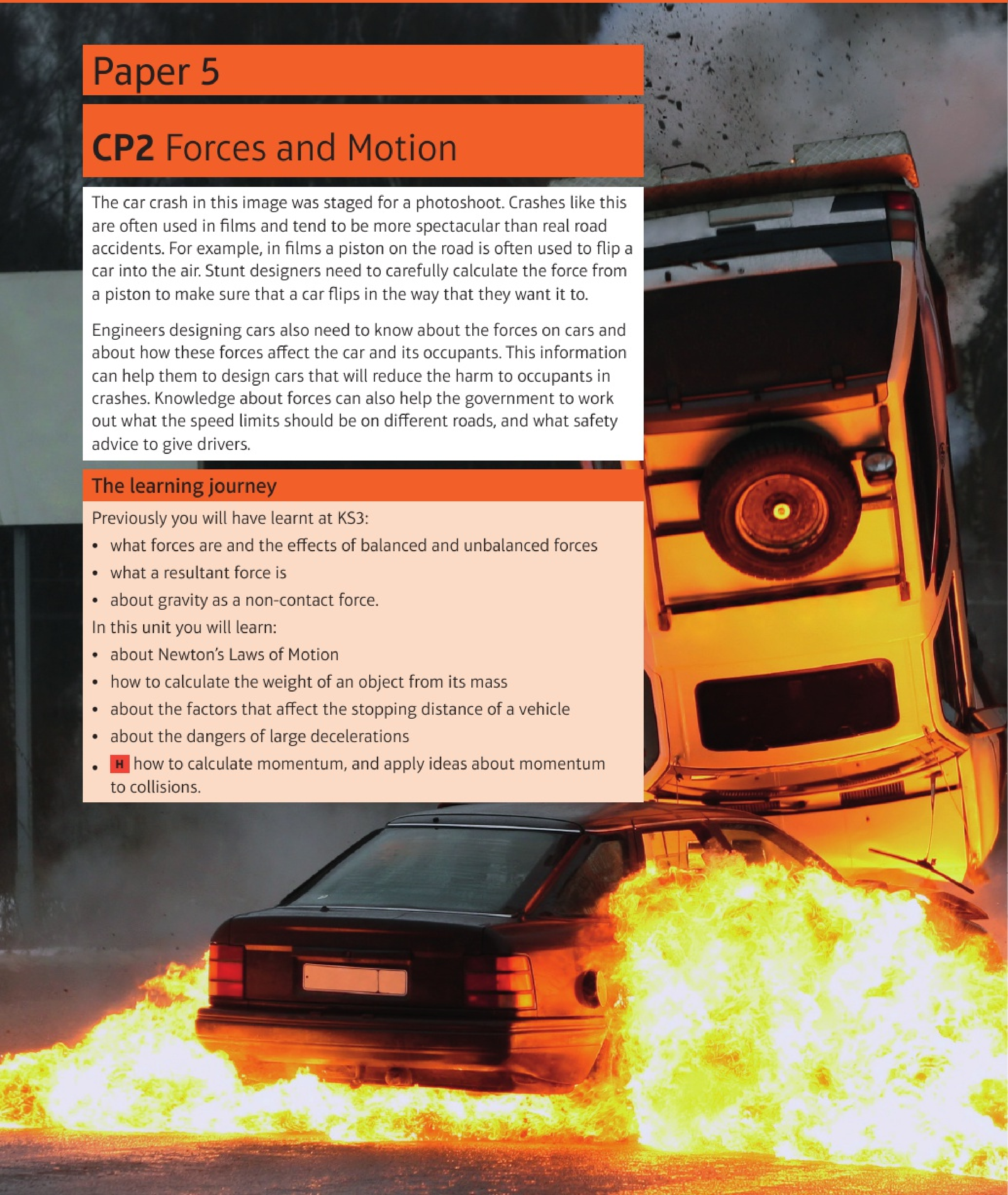
This answer could be improved by including information on the third statement and an explanation for the second statement.

Exam tip

Try to leave enough time to check through your answer. Make sure you have included everything that the question has asked for (in this example, the student should have covered all three statements).

Paper 5

CP2 Forces and Motion



The car crash in this image was staged for a photoshoot. Crashes like this are often used in films and tend to be more spectacular than real road accidents. For example, in films a piston on the road is often used to flip a car into the air. Stunt designers need to carefully calculate the force from a piston to make sure that a car flips in the way that they want it to.

Engineers designing cars also need to know about the forces on cars and about how these forces affect the car and its occupants. This information can help them to design cars that will reduce the harm to occupants in crashes. Knowledge about forces can also help the government to work out what the speed limits should be on different roads, and what safety advice to give drivers.

The learning journey

Previously you will have learnt at KS3:

- what forces are and the effects of balanced and unbalanced forces
- what a resultant force is
- about gravity as a non-contact force.

In this unit you will learn:

- about Newton's Laws of Motion
- how to calculate the weight of an object from its mass
- about the factors that affect the stopping distance of a vehicle
- about the dangers of large decelerations
- **H** how to calculate momentum, and apply ideas about momentum to collisions.

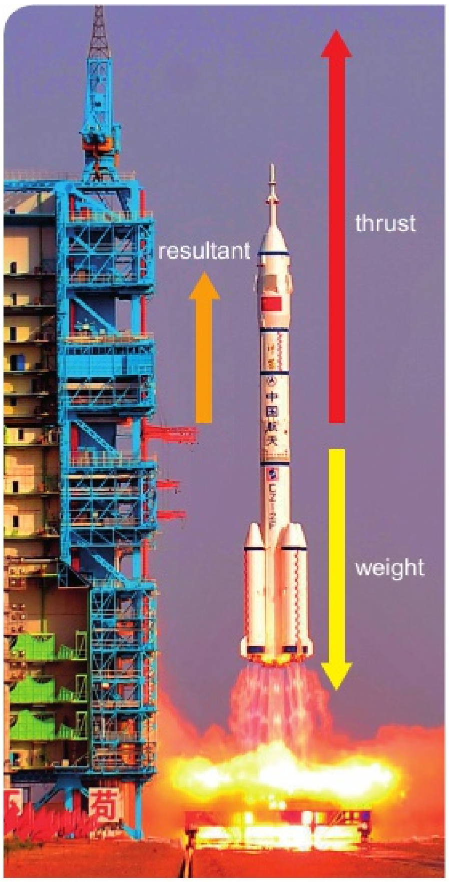
CP2a Resultant forces

Specification reference: P2.14

Progression questions

- What is the difference between the speed of an object and its velocity?
- How do we represent all the forces acting on an object?
- How do we calculate resultant forces?

A A 'wall of death' is a small arena with almost vertical sides. Motorcyclists ride around the walls, and won't fall as long as they keep moving!



B A Chang Zheng 2F rocket has a take-off weight of approximately 5000 kN, and thrust of about 13 000 kN (1 kN = 1000 N).

Scalars and vectors

The motorcyclist in photo A is moving at a constant **speed** but his **velocity** is changing all the time. This is because velocity is a **vector quantity**. It has a direction as well as a magnitude (size). Speed is a **scalar quantity**. It only has a magnitude.

When an object changes its velocity, it is accelerating. As **acceleration** is a change in a vector quantity (velocity), acceleration is also a vector.

1 A car is driving around a roundabout at 20 km/h. Explain whether or not:

5th **a** its speed is changing

7th **b** its velocity is changing.

Representing forces

Forces are vector quantities. It is important to know the direction in which a force is acting, as well as how big it is. We can draw diagrams to show the forces on objects to help us to think about the effects the forces will have. The size of the force is represented by the length of the arrows.

The thrust on the rocket in photo B is the upwards force from its engines. You can easily see from the diagram that the thrust is greater than its weight. The weight cancels out part of the thrust, so the overall upwards force is 8000 kN. This is called the **resultant force** on the rocket.

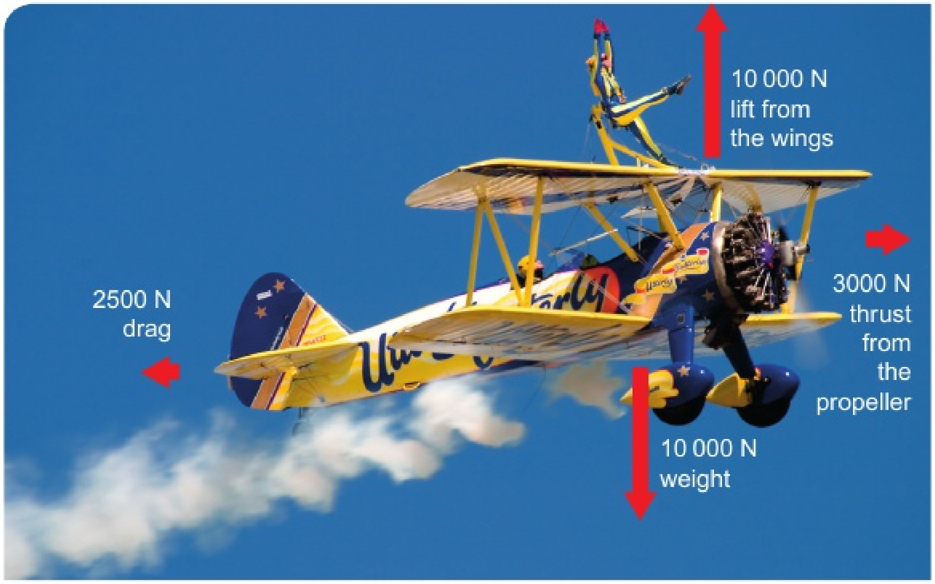
To work out the resultant of two forces:

- if the forces are acting in the same direction, add them
- if they are acting in opposite directions (as in photo B), subtract one from the other.

8th **2** **a** A cyclist is riding along a flat road without pedalling. The air resistance is 10 N and friction is 5 N. What is the resultant force on the bike?

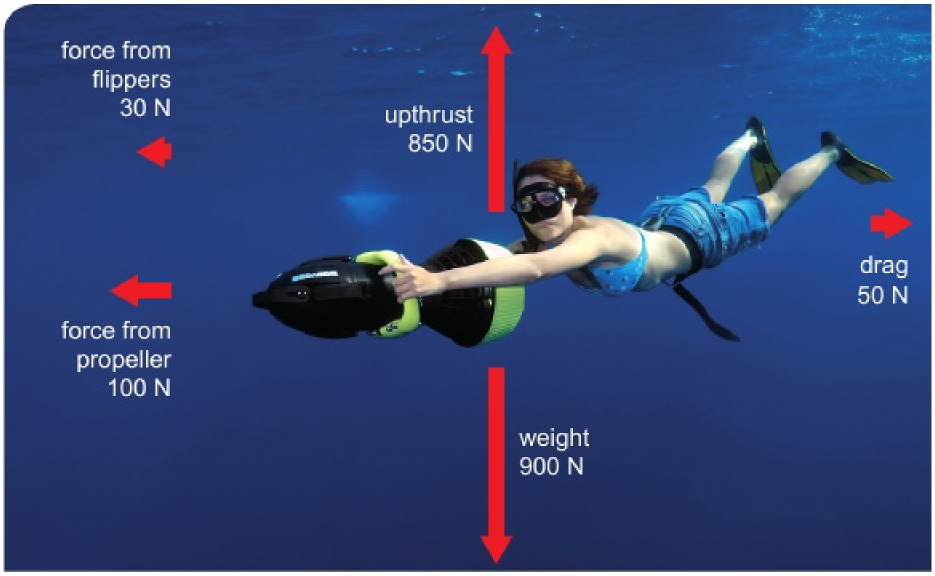
8th **b** What is the resultant force if the cyclist is pedalling with a force of 25 N?

The aeroplane in photo C has two forces acting in the vertical direction and two in the horizontal. We do not have to think about all four forces at one time to work out a resultant, because the two sets of forces are at right angles to each other. We can think about the two sets of forces separately.



C

If the resultant of all the forces on an object is zero, we say the forces are **balanced**. If there is a non-zero resultant force on an object, the forces are **unbalanced**.



D What are the forces on this diver?

Exam-style question

The forces on a car are balanced. State and explain the size of the resultant force on the car. *(2 marks)*

3 Calculate the resultant force on the aeroplane in photo C in the:

a vertical direction

b horizontal direction.

4 In photo C, are the forces balanced or unbalanced in the:

a vertical direction

b horizontal direction?

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Draw a concept map to show what you know about forces.

Extend

E1 Calculate the resultant force on the diver in photo D in the vertical direction and in the horizontal direction.

E2 Draw a diagram of the diver and add force arrows to show the two resultant forces.

CP2b Newton's First Law

Specification reference: P2.14; **H** P2.20; **H** P2.21

Progression questions

- What happens to the motion of an object when the forces on it are balanced?
- What can happen to the motion of an object when there is a resultant force on it?
- **H** What is centripetal force?

A Human cannonballs are propelled using unbalanced forces from compressed air or springs – not using explosives!

Sir Isaac Newton (1642–1727) worked out three 'laws' of motion that describe how forces affect the movement of objects.

Newton's First Law of motion can be written as:

- a moving object will continue to move at the same speed and direction unless an external force acts on it
- a stationary object will remain at rest unless an external force acts on it.

It is the overall resultant force that is important when you are looking at how the velocity of an object changes. Balanced forces (zero resultant force) will not change the velocity of an object. Unbalanced forces (non-zero resultant force) will change the speed and/or direction of an object.

7th **1** **a** What is the resultant force on the human cannonball in the vertical direction when she is flying through the air?

7th **b** How will this resultant force affect her velocity?

2 Look at photo C on the previous page again. Explain how the velocity of the aeroplane will change in the:

7th **a** vertical direction

7th **b** horizontal direction.

The ice yacht in photo B is not changing speed in the vertical direction. Its weight is balanced by an upwards force from the ice.

B An ice yacht can go much faster than a sailing boat in the same wind conditions.

3 A sailing boat has a forwards force of 300 N from the wind in its sails. It is travelling at a constant speed.

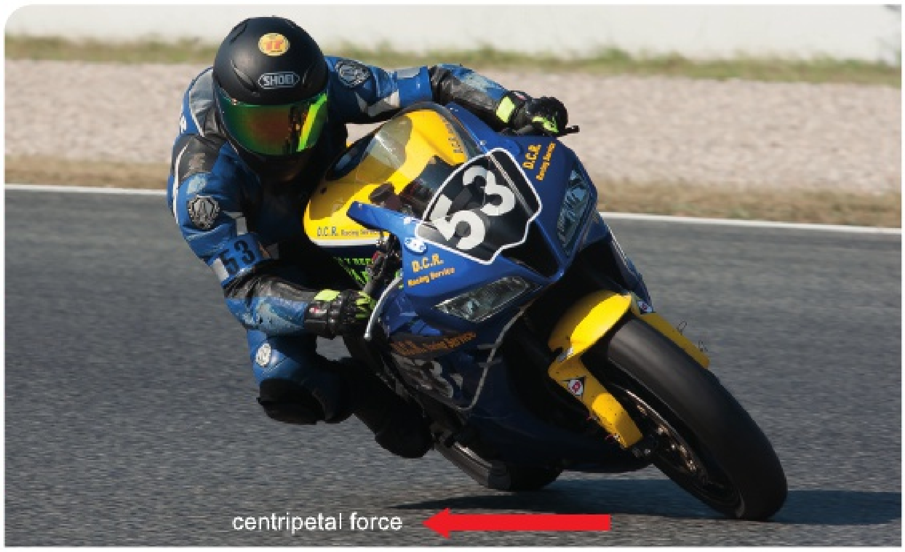
7th **a** What is the total force acting backwards on the sailing boat? Explain your answer.

8th **b** The ice yacht in photo B has the same force from its sails. Explain why its velocity will be increasing.

H Circular motion

C This fairground ride is accelerating the people in the chairs.

An object moving in a circle has changing velocity, even though its speed remains the same. The resultant force that causes the change in direction is called the **centripetal force**, and acts towards the centre of the circle. In photo C, the centripetal force is provided by tension in the wires holding the seats. Other types of force that can make objects move in circular paths include friction and gravity.



D The centripetal force here is supplied by friction between the tyres and the road.

9th **4** A satellite is in a circular orbit around the Earth. Explain how and why its velocity is continuously changing.

Exam-style question

A man is pushing a baby along the pavement in a pushchair. Friction is also acting on the pushchair. The pushchair is slowing down. Compare the horizontal forces on the pushchair. *(2 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 You are cycling along a flat road and your speed is increasing. Explain the resultant forces on you in the horizontal and vertical directions.

Extend

E1 Describe the forces on a human cannonball, from just before they are fired to when they land safely in a net, including how these forces affect their motion. You only need to consider forces and motion in the vertical direction.

E2 **H** Explain what a centripetal force is and describe three different kinds of force that can act as centripetal forces.

CP2c Mass and weight

Specification reference: P2.16; P2.17; P2.18

Progression questions

- What is the difference between mass and weight?
- What are the factors that determine the weight of an object?
- How do you calculate weight?

A The Huygens space probe used the air resistance from a parachute to balance its weight when it landed on Titan (one of Saturn's moons).

Mass is the quantity of matter there is in an object, and only changes if the object itself changes. For example, your mass increases when you eat a meal. **Weight** is a measure of the pull of gravity on an object and depends on the strength of gravity. The units for mass are kilograms. Weight is a force, so it is measured in newtons. Weight can be measured using a **force meter**, which has a scale in newtons. Many force meters contain a spring, which stretches as the force on it increases allowing the weight to be read off the scale.

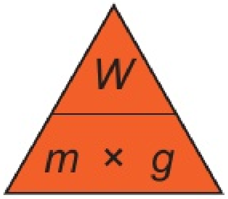
1 Suggest one way in which you can decrease your mass.

On Earth the **gravitational field strength** has a value of about 10 newtons per kilogram (N/kg). This means that each kilogram is pulled down with a force of 10 N. The gravitational field strength is different on other planets and moons.

The weight of an object can be calculated using the following equation:

$$\underset{(\text{N})}{\text{weight}} = \underset{(\text{kg})}{\text{mass}} \times \underset{(\text{N/kg})}{\text{gravitational field strength}}$$

This is often written as: $W = m \times g$



B This triangle can help you to change the subject of the equation. Cover up the quantity you want to find, and what you can see is the equation you need to use.

Worked examples

What is the weight of a 90 kg astronaut on the surface of the Earth?

$W = m \times g$

$W = 90\text{ kg} \times 10\text{ N/kg}$

$= 900\text{ N}$

A space probe has a weight of 3000 N on the Earth. What is its mass?

$m = \frac{W}{g}$

$= \frac{3000\text{ N}}{10\text{ N/kg}}$

$= 300\text{ kg}$

Did you know?

Gravity is not the same everywhere on the Earth. Your weight is greater standing at the North Pole than it would be standing at the equator.

2 A 300 kg space probe lands on Titan, where the gravitational field strength is 1.4 N/kg.

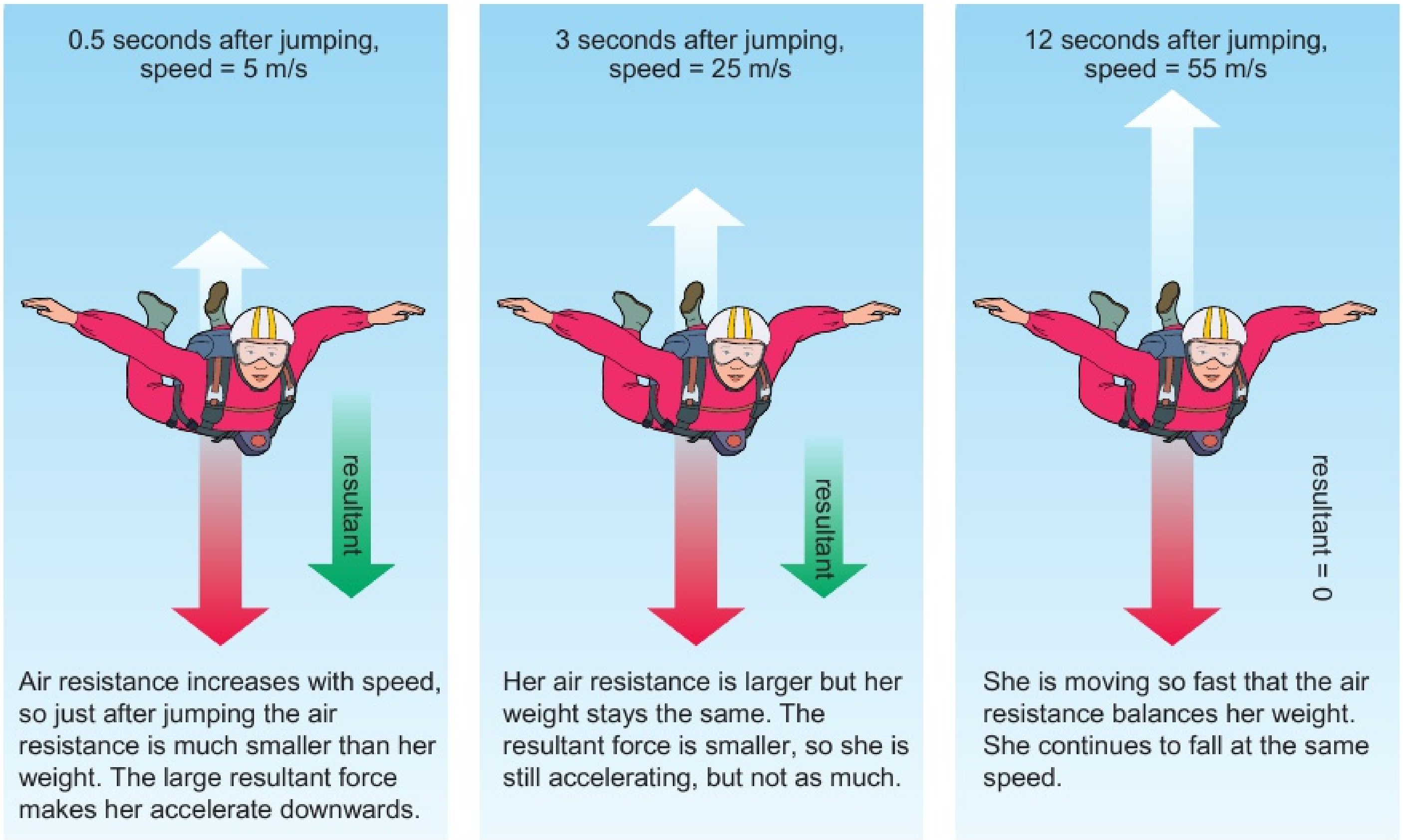
a What is its mass on Titan? Explain your answer.

b What is its weight on Titan?

3 A Mars rover has a mass of 185 kg. Its weight on Mars is 685 N. What is the gravitational field strength on Mars?

Forces on falling bodies

On Earth, a falling object has a force of air resistance on it as well as its weight. Figure C shows how the forces on a skydiver change during her fall.


0.5 seconds after jumping, speed = 5 m/s
resultant
3 seconds after jumping, speed = 25 m/s
resultant
12 seconds after jumping, speed = 55 m/s
resultant = 0

Air resistance increases with speed, so just after jumping the air resistance is much smaller than her weight. The large resultant force makes her accelerate downwards.

Her air resistance is larger but her weight stays the same. The resultant force is smaller, so she is still accelerating, but not as much.

She is moving so fast that the air resistance balances her weight. She continues to fall at the same speed.

C

4 Explain why the weight of the skydiver stays the same throughout the jump.

5 When the skydiver opens her parachute her air resistance increases very suddenly. Explain how this affects the resultant force and her velocity.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Write glossary entries for 'mass' and 'weight'.

S2 A cat has a mass of 2 kg. Calculate its weight on Earth.

Extend

E1 Write an encyclopaedia entry that explains the difference between mass and weight.

E2 A space probe on Titan has a weight of 280 N. Calculate its mass and its weight on Earth.

Exam-style question

The mass of a spanner on Earth is 0.2 kg, and its weight is 2 N.
The spanner is taken to the Moon as part of an astronaut's tool kit.

Compare the mass and weight of the spanner on the Moon and on the Earth. *(4 marks)*

CP2d Newton's Second Law

Specification reference: P2.15; H P2.22

Progression questions

- What are the factors that affect the acceleration of an object?
- How do you calculate the different factors that affect acceleration?
- H What is inertial mass and how is it defined?

A The safety rules for building Formula 1® cars include a limit to the engine force and a minimum mass for the car.

The acceleration of an object is a measure of how much its velocity changes in a certain time. Sir Isaac Newton's Second Law of Motion describes the factors that affect the acceleration of an object.

The acceleration in the direction of a resultant force depends on:

- the size of the force (for the same mass, the bigger the force the bigger the acceleration)
- the mass of the object (for the same force, the more massive the object the smaller the acceleration).

7th **1** The resultant force on a ball is not zero. What will happen to the ball?

8th **2** **a** The same force is used to accelerate a small car and a lorry. What will be different about their motions? Explain your answer.

8th **b** If you wanted to make the same two vehicles accelerate at the same rate, what can you say about the forces needed to do this? Explain your answer.

Did you know?

B A bike with low mass is so important for track racers that their bikes do not even have brakes! Racing rules state that these bikes must have a minimum mass of 6.8 kg.

Calculating forces

The force needed to accelerate a particular object can be calculated using the equation:

force = mass × acceleration
(N) (kg) (m/s^2)

This is often written as $F = m \times a$

1 newton is the force needed to accelerate a mass of 1 kg by 1 m/s^2.

Worked example

A motorcycle has a mass of 200 kg. What force is needed to give it an acceleration of 7 m/s^2?

$$\begin{aligned} F &= m \times a \\ &= 200\ \text{kg} \times 7\ \text{m/s}^2 \\ &= 1400\ \text{N} \end{aligned}$$

3 A car has a mass of 1500 kg. What force is needed to give it an acceleration of 4 m/s^2?

4 A force of 800 N accelerates the car in question 3. What is its acceleration?

H Inertial mass

The more massive an object is, the more force is needed to change its velocity (either to make it start moving or to change the velocity of a moving object). We define the **inertial mass** of an object as the force on it divided by the acceleration that force produces.

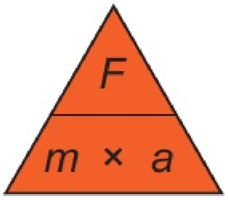
Calculating an object's inertial mass from values of force and acceleration gives the same mass value as that found by measuring the force of gravity on it.

5 A force of 160 N on a bicycle produces an acceleration of 2 m/s^2. What is the total inertial mass of the bicycle and its rider?

Exam-style question

A car accelerates at 2 m/s^2. The resultant force acting on the car is 3000 N.

Calculate the mass of the car. *(3 marks)*



C This triangle can help you to change the subject of the equation. Cover up the quantity you want to find, and what you can see is the equation you need to use.

D What do you need to know to work out whether the car or aeroplane has the greater acceleration?

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Look at photo A. Explain whether the Formula 1® rules are designed to set an upper or lower limit to the accelerations of the cars.

S2 Calculate the force needed to accelerate a 250 kg motorbike at 5 m/s^2.

Extend

E1 Look at photo D. Explain what you need to know to help you to work out which vehicle will have the greater acceleration.

E2 Explain why two objects dropped on the Moon will accelerate at the same rate, even when they have different masses.

CP2d Core practical – Investigating acceleration

Specification reference: P2.19

Aim

Investigate the relationship between force, mass and acceleration by varying the masses added to trolleys.

A

In drag racing, the aim is to get to the end of a straight track as quickly as possible, and so the most important feature of the bike is its acceleration. Drag racers can try to improve the performance of their bikes by changing the force produced by the engine and the tyres or by changing the mass of the bike.

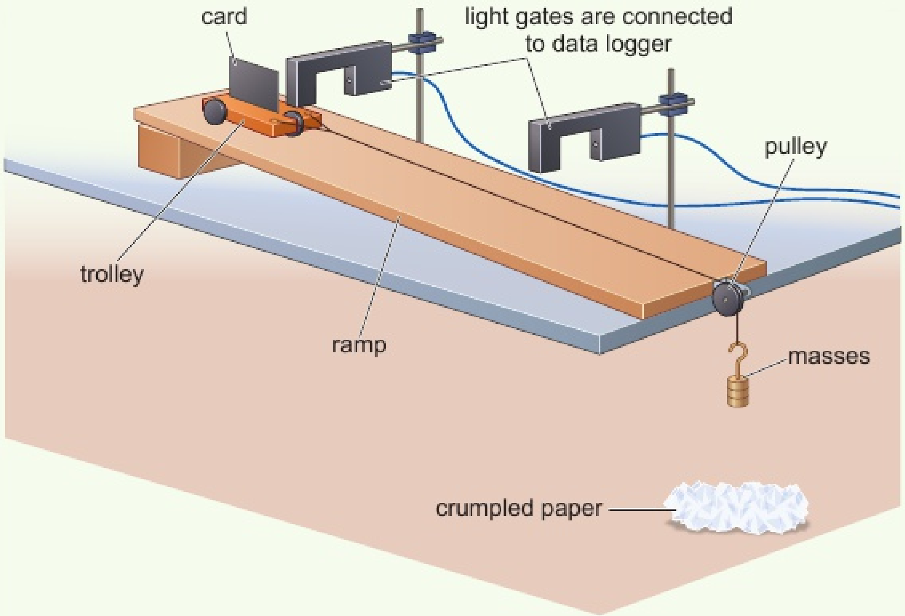
Your task

You are going to use trolleys as a model of a motorbike to investigate the effects that mass and force have on acceleration. The force will be provided by masses hanging on a string. You can vary the mass of the trolley by adding stacking masses to it.

Method

A Prop up one end of the ramp. Place a trolley on the ramp. Adjust the slope of the ramp until the trolley just starts to move on its own. Keep the ramp at this slope for the whole investigation. Set up the light gates and the pulley and string as shown in diagram B.

B Stick a piece of card to the top of the trolley. Measure the length of the card and write it down.



B apparatus for investigating acceleration

C Find the mass of the trolley and write it down.

D Put a mass on the end of the string. You will keep this mass the same for all your tests. You will have to decide what mass to use.

E Release the trolley from the top of the ramp and write down the speed of the trolley (from the datalogger) as it passes through each light gate. Also write down the time it takes for the trolley to go from one light gate to the other.

F Put a mass on top of the trolley. Keep the masses on the end of the string as they were before. Repeat step E.

G Repeat step E for other masses on top of the trolley. You will have to decide what masses to use, how many different masses you are going to test, and whether you need to repeat any of your tests.

H The steps above are investigating how the mass of the trolley affects the acceleration. If you wish to investigate the effect of force on acceleration, you need to keep the mass the same. However, the masses on the end of the string are also accelerating, along with the trolley, and it is the overall mass that you need to keep the same. You can do this by starting with a stack of masses on the trolley. Take one mass off the trolley and hang it on the end of the string. Then follow step E to measure the acceleration.

I Now transfer another mass from the trolley to the end of the string and find the acceleration again. Keep doing this until all the masses that started on the trolley have been transferred to the end of the string.

Exam-style questions

1 The light gates and datalogger record the speed of the trolley at the top of the ramp and at the bottom of the ramp, and also record the time the trolley takes to move between the two light gates. Describe how this information can be used to calculate the acceleration. *(2 marks)*

2 State the difference between mass and weight. *(1 mark)*

3 Explain one way in which you would stay safe while doing the experiments. *(2 marks)*

4 Make a list of the apparatus you need to carry out the method. *(2 marks)*

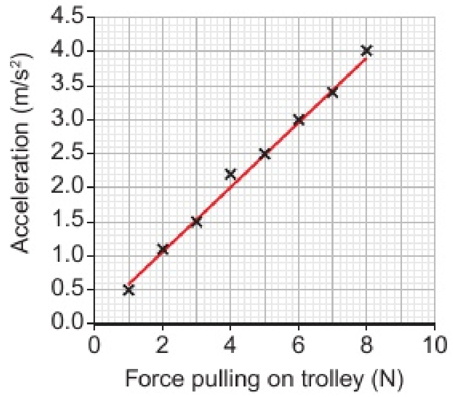
5 Explain why a light gate is needed at the top of the ramp as well as at the bottom. *(2 marks)*

6 Look at steps H and I. Explain why all the masses to be used in investigating the effect of the force on acceleration have to be on the trolley to start with. *(3 marks)*

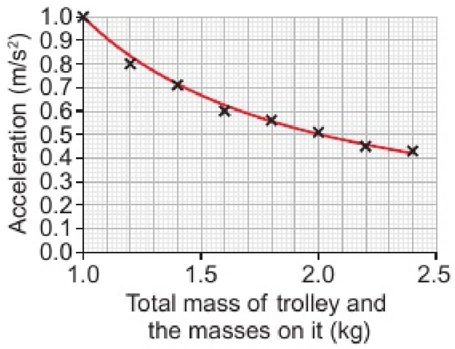
7 Use the results shown in graph C to draw a conclusion for this part of the investigation. *(1 mark)*

8 Look at graph D.

- **a** Use graph D to draw a conclusion for this part of the investigation. *(1 mark)*
- **b** Explain how you would present the data in graph D to allow you to draw a better conclusion. *(2 marks)*



C



D

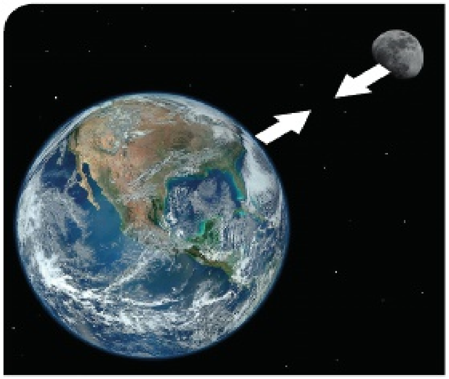
CP2e Newton's Third Law

Specification reference: P2.23; **H** P2.23

Progression questions

- What does Newton's Third Law tell us?
- How does Newton's Third Law apply to stationary objects?
- **H** How do objects affect each other when they collide?

A The dog is not moving. What are the forces acting here?



B The Earth attracts the Moon with the same force as the Moon attracts the Earth.

2 You are standing leaning on a wall. Draw a sketch to show this (a stick man will do) and add arrows to show an action–reaction pair of forces acting in the:

9th **a** vertical direction

9th **b** horizontal direction.

7th **3** For the situation in question 2, describe the balanced forces on you acting in the vertical direction.

Newton's Third Law is about the forces on two different objects when they interact with each other. This interaction can happen:

- when objects touch, such as when you sit on a chair
- at a distance, such as the gravitational attraction between the Earth and the Moon.

There is a pair of forces acting on the two interactive objects, often called **action–reaction forces**. The two forces are always the same size and in opposite directions. They are also the same type of force. In photo A the rope and the dog are both exerting pulling forces on each other. In photo B the two forces are both gravitational forces.

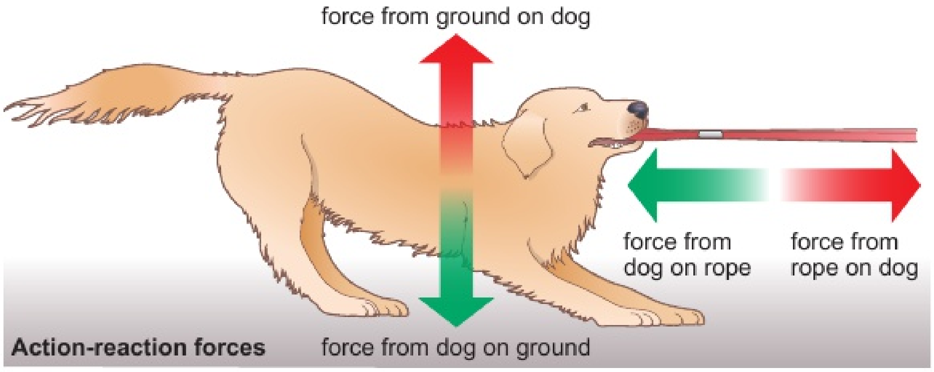
Photo A shows an **equilibrium** situation, because nothing is moving. A force in the rope is pulling on the dog but the dog is also pulling on the rope.

8th **1** Think about the vertical forces in photo A. One force is the weight of the dog pushing down on the ground. What is the other force in this pair?

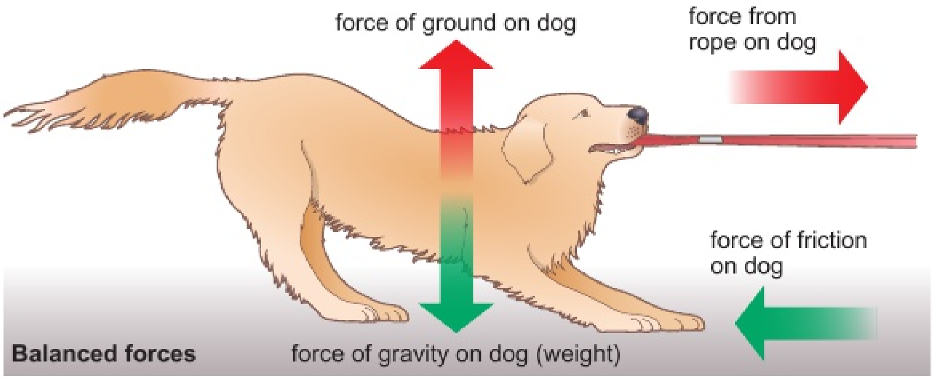
The weight of a dog on the ground is equal to the force pushing up on the dog from the ground. In photo A there is another pair of action–reaction forces acting on the rope and the dog – there is a force from the dog on the rope and a force from the rope on the dog.

Action–reaction forces are not the same as balanced forces. In both cases the sizes of the forces are equal and act in opposite directions, but:

- action–reaction forces act *on different objects.*
- balanced forces all act *on the same object*



Ci

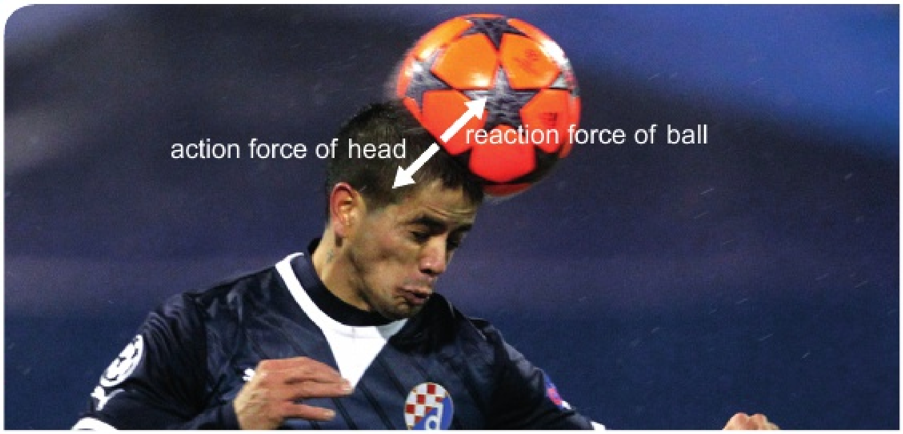


Cii

H Collisions

We can apply the idea of action–reaction forces to what happens when things collide. In photo D, the ball will bounce off the footballer's head. His head exerts a force on the ball, but the ball also exerts a force on his head, as you can feel if you have ever tried heading a ball!

The action and reaction forces that occur during the collision are the same size, but they do not necessarily have the same effects on the two objects, because the objects have different masses.



D Action–reaction forces during a collision.

8th **4** Describe the action–reaction forces when a ball bounces on the ground.

8th **5** Look at photo D. The player's head and the ball both change velocity during the collision. Describe the effects on the two objects and explain why the effects are different.

Exam-style question

A student is using a force meter to find the weight of an apple. Describe an action-reaction pair of forces in this situation. *(1 mark)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe the action–reaction forces when you sit in a chair. Describe how these forces are different to a pair of balanced forces acting on you.

Extend

E1 Two teams are having a tug-of-war. Make a sketch and add labelled arrows to show three action–reaction force pairs and three pairs of balanced forces.

E2 H A ball is released a metre above the surface of the Earth. Describe the action–reaction forces due to gravity on the ball and the Earth. Describe the forces when the ball and the Earth collide. Explain how the effects on the two objects are different.

CP2f Momentum

Specification reference: H P2.23; H P2.24; H P2.25; H P2.26

Progression questions

- H How is momentum calculated?
- H How is momentum related to force and acceleration?
- H What happens to momentum in collisions?

H

A The damage caused by a wrecking ball depends on its mass and how fast it is moving when it hits.

force, mass and acceleration	$F = m \times a$
change in velocity and time	$a = \frac{v - u}{t}$

C equations involving acceleration

Did you know?

The largest ships are oil tankers. It can take several miles for a moving oil tanker to come to a stop.

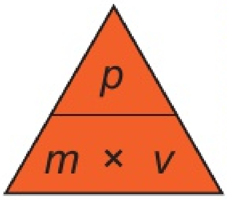
4 A 1000 kg car accelerates from rest to 15 m/s in 15 seconds. What resultant force caused this?

Momentum is a measure of the tendency of an object to keep moving – or of how hard it is to stop it moving. The momentum of an object depends on its mass and its velocity. Momentum depends on a vector quantity (velocity), and is also a vector.

Momentum is calculated using this equation:

$$\underset{(\text{kg m/s})}{\text{momentum}} = \underset{(\text{kg})}{\text{mass}} \times \underset{(\text{m/s})}{\text{velocity}}$$

This can also be written as $p = m \times v$, where p stands for momentum.



B

1 Explain why a motorcycle travelling at 30 m/s has less momentum than a car travelling at the same velocity.

2 A 500 kg wrecking ball is moving at 10 m/s when it hits a building. What is its momentum?

3 The same ball at a different time has a momentum of 1500 kg m/s. What is its velocity?

Momentum and acceleration

Table C shows two equations involving acceleration. These can be combined to give:

$$\text{force} = \frac{\text{mass} \times \text{change in velocity}}{\text{time}} \quad \text{or} \quad \frac{m(v - u)}{t}$$

where v is the final velocity and u is the starting velocity.

As mass × velocity is the momentum of an object, this equation can also be written as:

$$\text{force} = \frac{\text{change in momentum}}{\text{time}} \quad \text{or} \quad \frac{mv - mu}{t}$$

Worked example

A 2000 kg car accelerates from 10 m/s to 25 m/s in 10 seconds. What resultant force produced this acceleration?

$$\text{force} = \frac{mv - mu}{t}$$

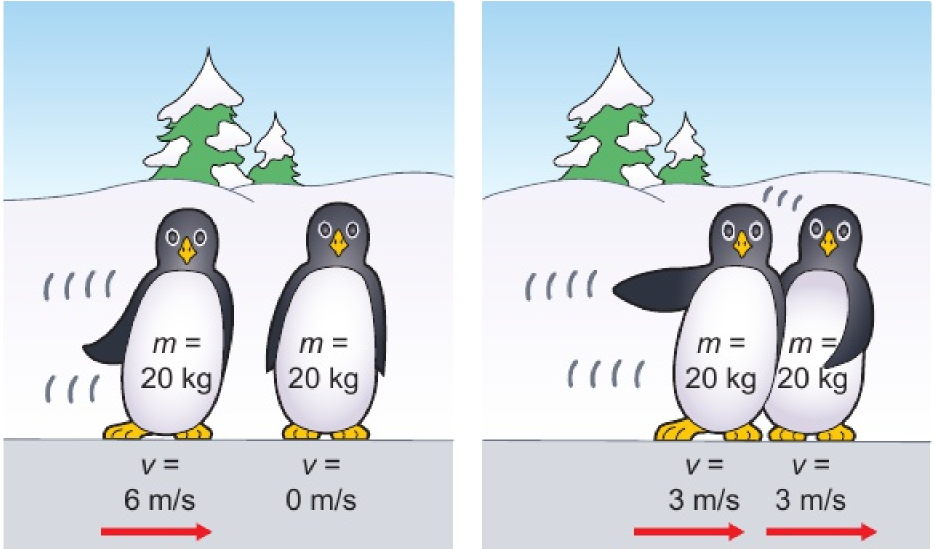
$$= \frac{2000\text{ kg} \times 25\text{ m/s} - 2000\text{ kg} \times 10\text{ m/s}}{10\text{ s}}$$

$$= \frac{50\,000\text{ kg m/s} - 20\,000\text{ kg m/s}}{10\text{ s}}$$

$$= 3000\text{ N}$$

H Momentum and collisions

When moving objects collide the total momentum of both objects is the same before the collision as it is after the collision, as long as there are no external forces acting. This is known as **conservation of momentum**. Remember, momentum is a vector so you need to consider direction when you add the quantities together. If two objects are moving in opposite directions, we give the momentum of one object a positive sign and the other a negative sign.



before collision

after collision

E

5 Look at diagram E.

a Calculate the momentum of each penguin before they collide.

b Calculate the total momentum before the penguins collide.

c In which direction is the total momentum before the collision?

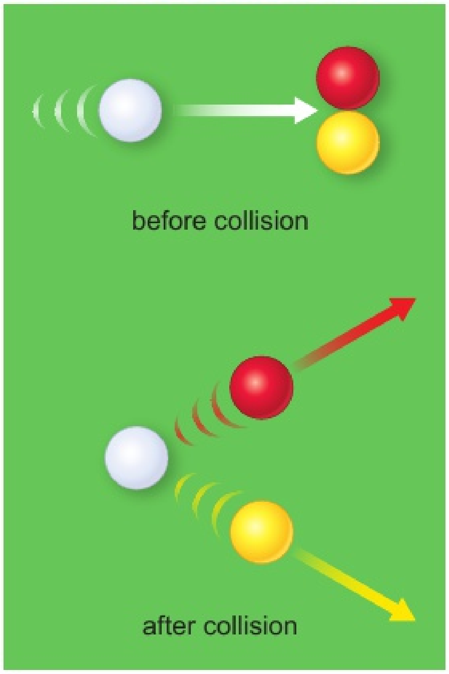
d What is the total momentum after the collision and in which direction?

e Explain whether momentum has been conserved.

Exam-style question

A car has a mass of 1800 kg. It is moving with a velocity of 35 m/s.

Calculate the momentum of the car. *(3 marks)*



D The total momentum of the two coloured balls will be the same as the momentum of the white ball that hit them.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Two 5000 kg railway trucks are travelling at 5 m/s in opposite directions when they collide. After the collision they are stationary. Show that momentum is conserved.

Extend

E1 A 1 g bullet is travelling at 300 m/s when it enters a stationary 1 kg block of wood. The impact of the bullet makes the wood move. What is the speed of the block immediately after the impact? Explain how you worked out your answer.

CP2g Stopping distances

Specification reference: P2.27; P2.28; P2.29; P2.30

Progression questions

- How are human reaction times measured?
- What are typical human reaction times?
- What are the factors that affect the stopping distance of a vehicle?

Did you know?

Until 1896 all 'self-propelled' vehicles had to have a man walking in front with a red flag, to warn other road users that it was coming.

A More than 130 vehicles were involved in this crash and over 200 people were injured.

When a driver sees a problem ahead, their vehicle will travel some distance while the driver reacts to the situation. This is called the **thinking distance**. The vehicle will then go some distance further while the brakes are working to bring it to a halt. This is called the **braking distance**. The overall **stopping distance** for any road vehicle is the sum of the thinking and braking distances.

stopping distance = thinking distance + braking distance

5th **1** Why is it important for drivers to know their stopping distances?

6th **2** For a thinking distance of 5 m and a braking distance of 12 m, what is the overall stopping distance?

Reaction times

A **reaction time** is the time between a person detecting a **stimulus** (such as a flashing light or a sound) and their **response** (such as pressing a button or applying the brakes in a car). Response times can be measured using computers or electric circuits that measure the time between a stimulus and a response.

The typical reaction time to a visual stimulus, such as a computer screen changing colour, is about 0.25 seconds. However this time can be much longer if the person is tired, ill or has been taking drugs or drinking alcohol. Distractions, such as using a mobile phone, can also increase reaction times.

B A driving simulator can be used to test reaction times in a realistic situation.

6th **3** Explain why the thinking distance depends on:

a the driver's reaction time **b** the speed of the car.

6th **4** Suggest why the reaction time measured in a driving simulator might be longer than the time measured using a test on a computer.

6th **5** Explain why there are legal limits for the amount of alcohol drivers are allowed in their blood.

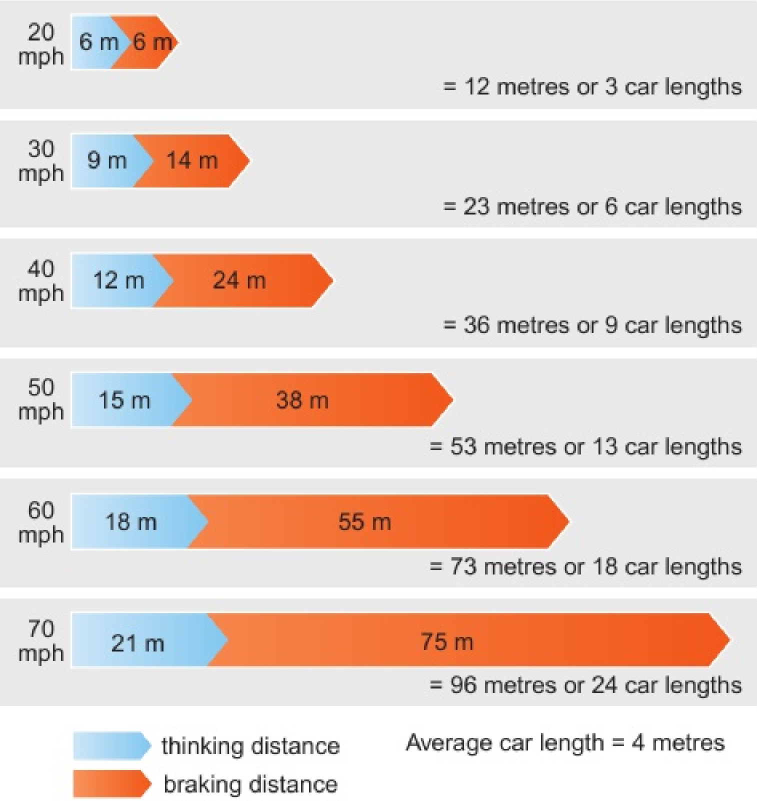
Braking distances

Car brakes use friction to slow the car down. If the brakes are worn, they create less friction and do not slow the vehicle as effectively. Friction between the tyres and road is also important. If the road is wet or has loose gravel on it, or if the tyres are worn, there is less friction and the braking distance is increased.

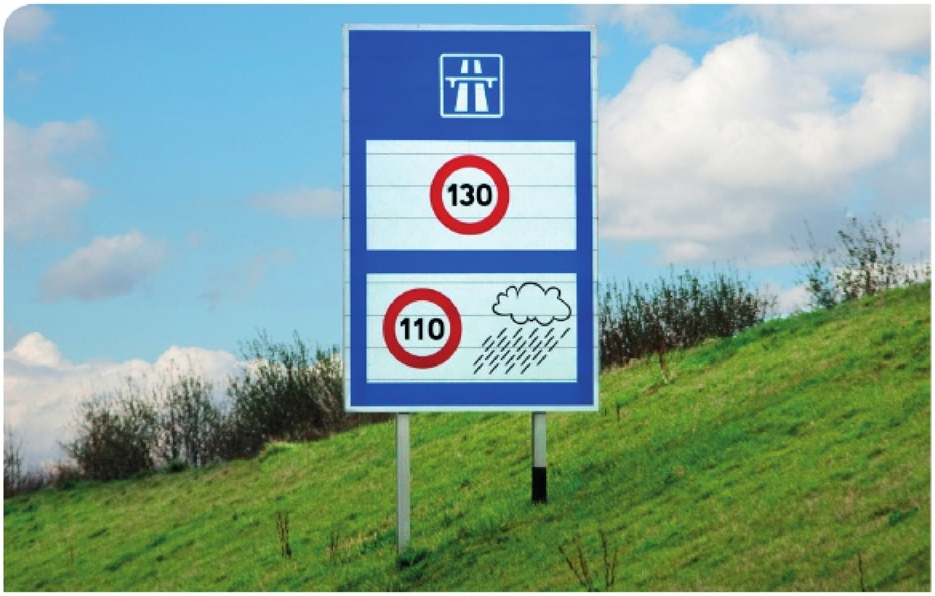
If a vehicle has more mass, more force is needed to decelerate it. So if the same amount of friction is used to stop a vehicle, a heavier vehicle will travel further than a lighter one (it has a greater braking distance).

6 Why are the overall stopping distances for cars less than for lorries?

7 Look at photo D. Suggest why there are two separate speed limits.



C The Highway Code shows typical stopping distances for a family car.



D This sign is from an autoroute (motorway) in France. The speed limits are in km/h.

Exam-style question

Explain how thinking distance and braking distance depend on the speed of the vehicle. *(4 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 List the factors that affect stopping distance. State whether each factor affects the thinking distance or the braking distance, and how they affect this distance.

Extend

E1 The crash in photo A happened in a sudden patch of fog. Write a paragraph for a road-safety website to explain why fog can be a hazard on the roads, and what drivers can do to avoid crashing in foggy conditions.

CP2h Crash hazards

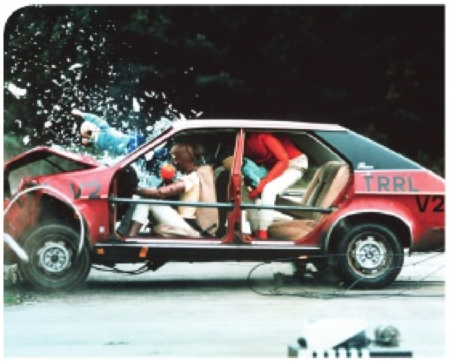
Specification reference: H P2.26; H P2.31

Progression questions

- What are the dangers caused by large decelerations?
- How can the hazards of large decelerations be reduced?
- H How can you use momentum to calculate the forces involved in crashes?

A The amount of damage caused by a collision depends on the mass of the lorry and on how fast it was travelling.

B The large forces in road collisions injure or kill people and damage cars.



C Forces on humans can result from hitting the dashboard or steering wheel, or if other passengers hit them.

In a car crash, the vehicles involved come to a stop very quickly. Slowing down is a **deceleration** (or a negative acceleration). The force needed for any kind of acceleration depends on the size of the acceleration and on the mass of the object.

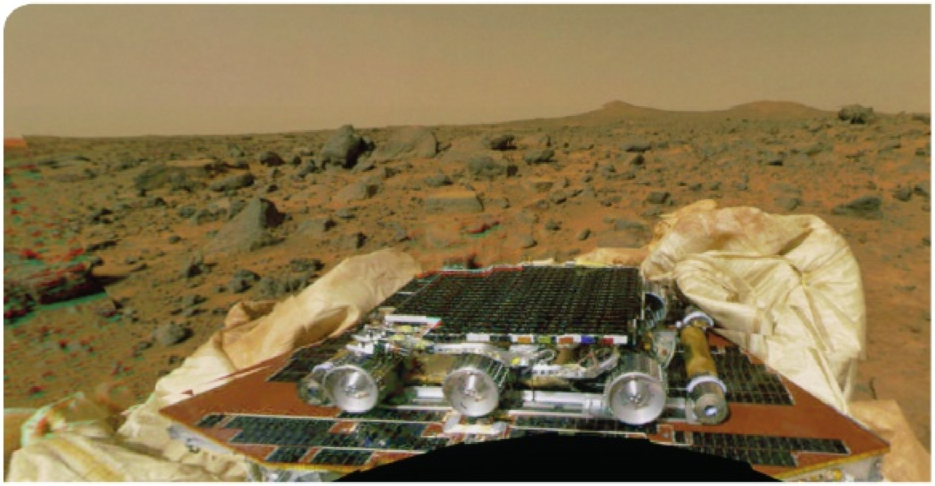
1 Explain why the force on a vehicle in a crash is larger:

8th **a** if the vehicle is moving faster before the crash

8th **b** for a lorry than for a car travelling at the same speed.

Modern cars have lots of safety features built into them to help to reduce the forces on the occupants in a collision. **Crumple zones** are built into the front (and sometimes the back) of cars. If the car hits something it takes a little time for this crumpling to happen, so the deceleration of the car is less and the force on the car is also less than if it had a more solid front.

Photo C also shows that the passengers do not stop moving when the car stops! Seat belts hold the passengers into the car, so the effect of the crumple zone reduces the forces on the passengers as well as on the car. Airbags increase the time it takes for a person's head to stop in a collision.



D Airbags were used to help the Mars Pathfinder to land safely by increasing the time for the probe to hit the ground, and so reducing the force on it..

H

The force in a road collision depends on the change of momentum as the car comes to a stop. You have seen (in Topic CP2f Momentum) that we can use the equation below to calculate the force:

$F = \frac{mv - mu}{t}$, where u is initial velocity and v is final velocity.

Worked example

A 1500 kg car is travelling at 15 m/s (just over 30 mph) when it hits a wall. It comes to a stop in 0.07 seconds. What is the force acting on the car?

$$\text{force} = \frac{1500\,\text{kg} \times 0\,\text{m/s} - 1500\,\text{kg} \times 15\,\text{m/s}}{0.07\,\text{s}}$$

$$= \frac{-22\,500}{0.07}$$

$$= -321\,429\,\text{N}$$

The negative sign shows that the force is in the opposite direction to the original motion.

10th **4** **a** **H** An 1800 kg car travelling at 20 m/s stops in 0.03 seconds when it hits a wall. What is the force on it?

9th **b** **H** Explain why this force is different to the one in the worked example. Give as many reasons as you can.

Exam-style question

Explain why a crumple zone only reduces the force on vehicle passengers if they are wearing seat belts. *(4 marks)*

7th **2** Look at photo C. Explain why front *and* back seat passengers in a car should wear seat belts.

8th **3** Bubble wrap is a plastic covering with many air bubbles. How do you think bubble wrap protects fragile items?

Did you know?

Many people have survived falls from aeroplanes without parachutes. In 2004, skydiver Christine McKenzie's parachute failed – she escaped with only a cracked pelvis because she fell into some power lines which slowed her down before she hit the ground.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe two ways of reducing the forces in a collision, and explain how they work.

Extend

E1 **H** Use calculations to show the effects of velocity, mass and crumple zones on the forces acting in a road collision. You will need to find or estimate values for speed, mass and the change in length of a crumple zone in a crash.

Stopping distances

The stopping distance of a vehicle is affected by its mass, its speed and the state of its brakes.

Explain how these factors affect the stopping distance, using ideas about forces and acceleration. (6 marks)

Student answer

The stopping distance is longer if the car is going faster or has a larger mass. If its brakes are working well, the stopping distance is shorter [1]*. The deceleration of the car depends on the force applied, which depends on how good the brakes are, so if the brakes are good the deceleration is more and it can stop sooner* [2]*. The deceleration also depends on the weight* [3]*, so if the brakes are the same* [4] *the deceleration will be less with a heavier car so it will go further while it is stopping.*

[1] This part of the answer describes how each factor affects the stopping distance.

[2] This explains how the state of the brakes affects the stopping distance.

[3] The student should refer to mass here, not weight.

[4] This would have been clearer if the student had referred to the *force* from the brakes being the same.

Verdict

This is an acceptable answer. It shows a good understanding of some of the factors that affect stopping distances. The answer clearly states how each factor affects the stopping distance, and provides good explanations for two of the factors. The use of scientific language is generally good, although with a mistake about weight and mass.

This answer could be improved by including an explanation of how the speed of a vehicle affects the stopping distance, and making sure that correct scientific words are used.

Exam tip

In this example the command word is 'explain' so you need to say how *and why* each factor affects the stopping distance.

Paper 5

CP3 Conservation of Energy

This is a solar power station at Sanlúcar la Mayor in Seville, Spain. Rings of mirrors focus energy from the Sun into a central furnace where water is heated to make steam. The steam is used to turn turbines, which drive generators to make electricity in a similar way to a normal power station.

In this unit you will learn about the ways in which energy can be transferred and stored, how to reduce energy transfers, and the renewable and non-renewable resources we use in everyday life.

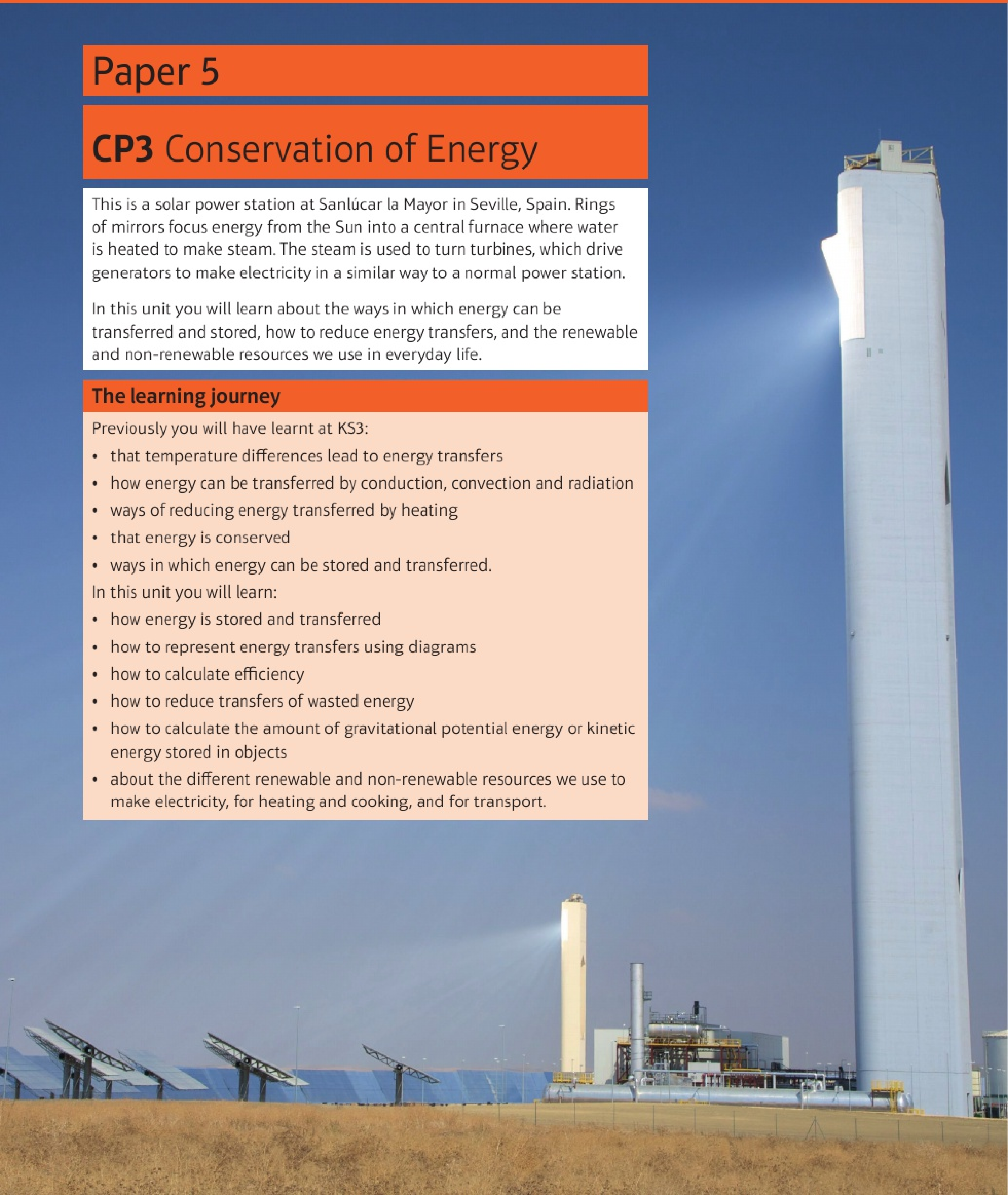
The learning journey

Previously you will have learnt at KS3:

- that temperature differences lead to energy transfers
- how energy can be transferred by conduction, convection and radiation
- ways of reducing energy transferred by heating
- that energy is conserved
- ways in which energy can be stored and transferred.

In this unit you will learn:

- how energy is stored and transferred
- how to represent energy transfers using diagrams
- how to calculate efficiency
- how to reduce transfers of wasted energy
- how to calculate the amount of gravitational potential energy or kinetic energy stored in objects
- about the different renewable and non-renewable resources we use to make electricity, for heating and cooking, and for transport.

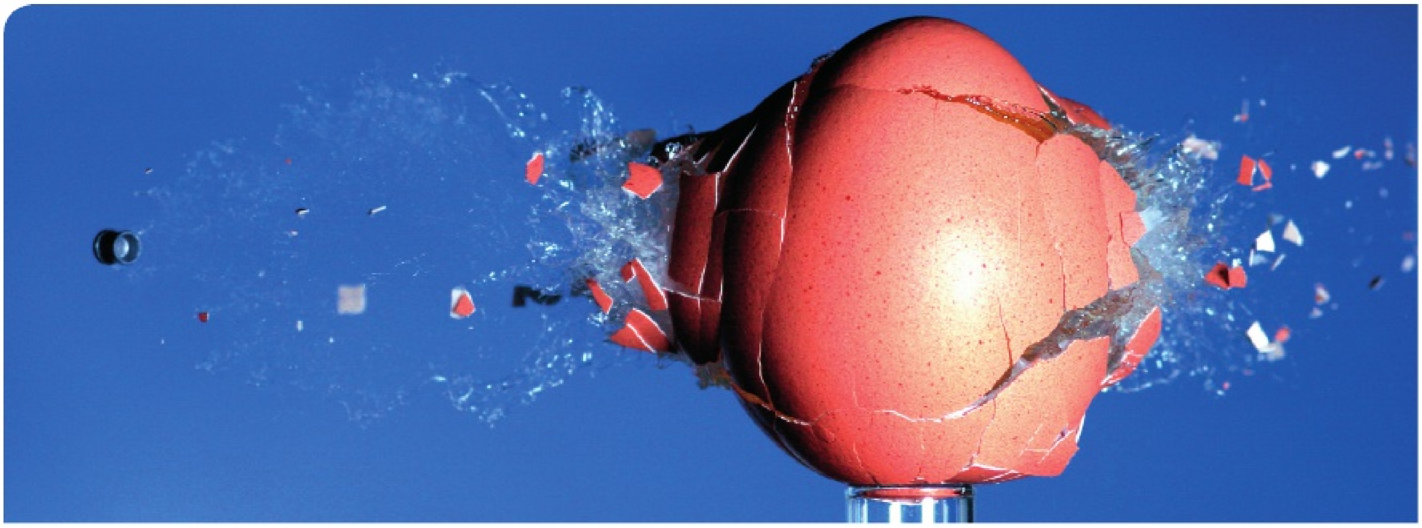


CP3a Energy stores and transfers

Specification reference: P3.3; P3.4; P3.5; P3.6; P3.8

Progression questions

- How is energy transferred between different stores?
- How can we represent energy transfers in diagrams?
- What happens to the total amount of energy when energy is transferred?



A What energy stores and transfers are involved as the bullet goes through the egg?

Energy is stored in different ways. Energy stored in food, fuel and batteries is often called **chemical energy**. Energy can also be stored in moving objects (**kinetic energy**), hot objects (**thermal energy**), in stretched, squashed or twisted materials (**strain energy** or **elastic potential energy**) and in objects in high positions (**gravitational potential energy**). Energy stored inside atoms is called **atomic energy** or **nuclear energy**.

Energy can be transferred between different stores. In photo A, some of the kinetic energy stored in the moving bullet is transferred to the egg by forces. Some of this energy is stored in the moving fragments of the egg, and some will heat up the egg.

When an electrical kettle is used to heat water, energy transferred to the kettle by electricity ends up as a store of thermal energy in the hot water. As the hot water is at a higher temperature than the kettle and the surroundings, some energy is transferred to these things by heating. Energy can also be transferred by light and sound.

Conservation of energy

In physics, a **system** describes something in which we are studying changes. An electrical kettle and its surroundings form a simple system. Energy cannot be created or destroyed. It can only be transferred from one store to another. This is called the **law of conservation of energy**. This means that the total energy transferred by a system is the same as the energy put into the system. The units for measuring energy are **joules** (J).

5th **1** Describe the changes in energy stores when a car accelerates.

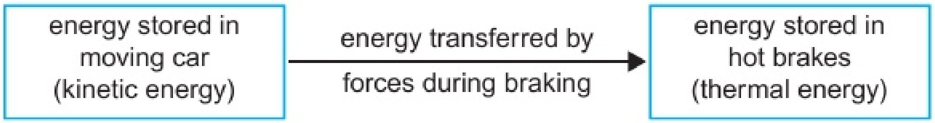
6th **2** A ball thrown upwards has a store of kinetic energy as it leaves the person's hand. Describe the changes in energy stores as the ball rises and then falls again.

5th **3** List the ways in which energy can be transferred that are mentioned on this page.

Although energy is always conserved, it is not always transferred into forms that are useful. Think of the kettle – the energy stored in the hot water is useful, but the energy stored in the kettle itself and in the surroundings is not.

Energy diagrams

We represent energy stores and transfers using diagrams, such as diagram B.


energy stored in moving car (kinetic energy)
energy transferred by forces during braking
energy stored in hot brakes (thermal energy)

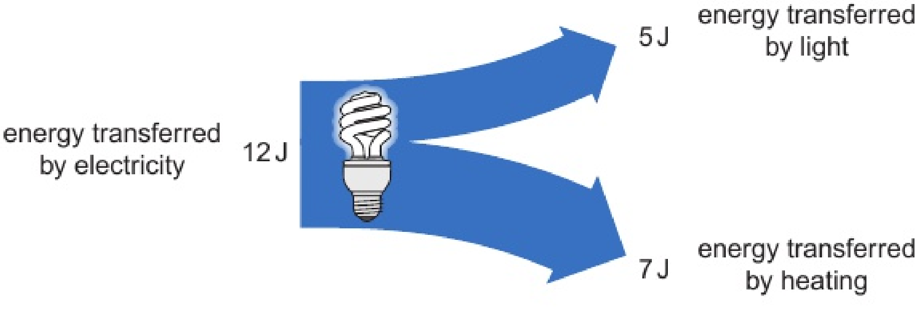
B A flow diagram showing the energy transfers when a car brakes.

Did you know?

The energy transferred by the braking force can increase the temperature of brakes so much that they glow red.

C

A **Sankey diagram** shows the amount of energy transferred. The width of the arrows represents the amount of energy in joules.


energy transferred by electricity
12 J
5 J
energy transferred by light
7 J
energy transferred by heating

D energy transfers in a light bulb

7th **7** Sketch a Sankey diagram for a kettle using the energy values given in question 4.

Exam-style question

a Draw a diagram to represent the energy transfers in a television. *(3 marks)*

b Identify the useful energy transfers in the television. *(1 mark)*

6th **4** 1000 J of energy is transferred to a kettle. 850 J ends up stored in the hot water in the kettle. Explain how much energy is transferred to the kettle itself and its surroundings.

7th **5** Look at diagram B. The car's brakes do not stay hot. Describe the final energy store in this system.

7th **6** **a** Draw an energy transfer diagram similar to diagram B for the bullet and egg in photo A.

7th **b** Describe how your diagram would be different if it were a car hitting a wall.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe the energy stores and transfers when you climb up to a high diving board and then jump into a swimming pool.

Extend

E1 A light bulb has 25 J of energy transferred to it every second, and 10 J of energy are transferred to the surroundings by light. Draw a Sankey diagram to show the energy transfers and explain how you worked out the amount of energy transferred by heating.

CP3b Energy efficiency

Specification reference: P3.7; P3.9; P3.11; **H** P3.12

Progression questions

- What does efficiency mean?
- How do we calculate the efficiency of an energy transfer?
- How can we reduce unwanted energy transfers in machines?

A Oiling the chain on a bicycle makes pedalling it much easier.

When a light bulb is switched on, most of the energy supplied to it by electricity is transferred to the surroundings by heating. This energy is **dissipated** (it spreads out) and cannot be used for other useful energy transfers – it is wasted.

Most machines waste energy when they get hot. Whenever two moving parts touch each other, friction causes them to heat up. The thermal energy stored in the hot machine is transferred to the surroundings by heating, which dissipates the energy. This energy is wasted energy.

Friction between moving parts can be reduced by **lubrication**. Oil or other liquids, and sometimes even gases, can be used as lubricants.

Did you know?

When two sticks are rubbed together the temperature rise can be used to start a fire. In this case the energy transferred by heating is useful!

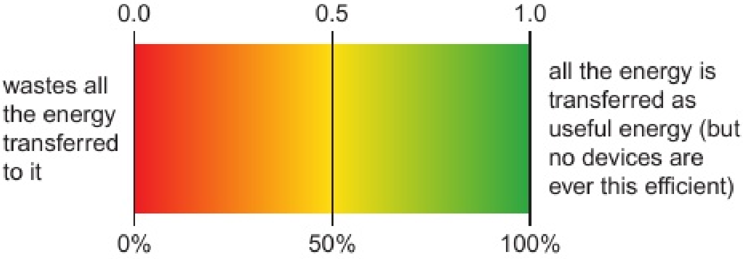
B

6th **1** **a** Explain why it is harder to pedal a bicycle if the chain needs oiling.

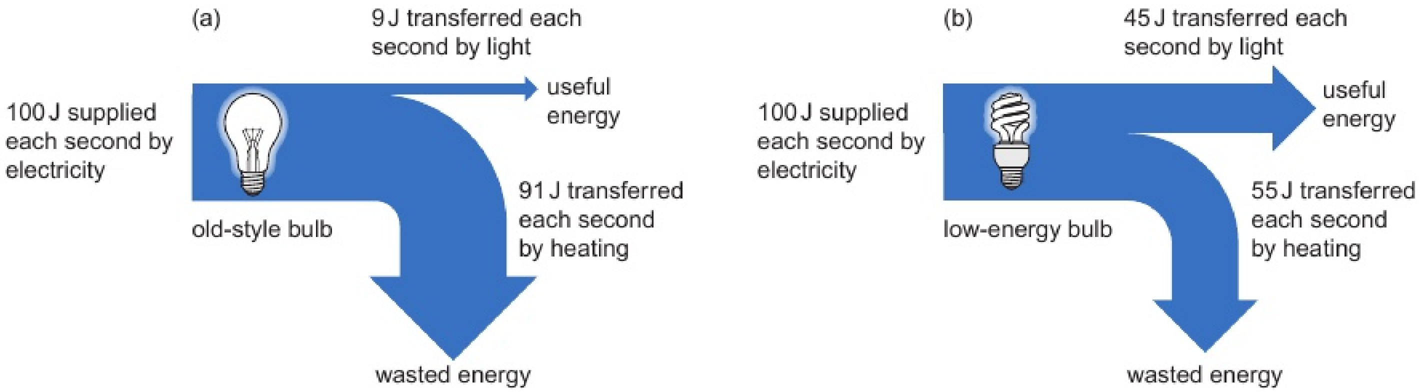
7th **b** When you pedal a bicycle, how is wasted energy transferred to the surroundings?

Efficiency

Efficiency is a way of describing how good a machine is at transferring energy into useful forms. The efficiency of a machine is given as a number between 0 and 1. The higher the number, the more efficient the machine. This is shown in diagram C.


0.0
0.5
1.0
wastes all the energy transferred to it
all the energy is transferred as useful energy (but no devices are ever this efficient)
0%
50%
100%

C The efficiency of a machine is sometimes given as a percentage.


(a)
9 J transferred each second by light
useful energy
100 J supplied each second by electricity
91 J transferred each second by heating
old-style bulb
wasted energy
(b)
45 J transferred each second by light
useful energy
100 J supplied each second by electricity
55 J transferred each second by heating
low-energy bulb
wasted energy

D Modern low-energy bulbs are more efficient than old-style bulbs.

2 Look at diagram D. How can you tell from these diagrams that modern low-energy bulbs are more efficient?

The efficiency of a device can be calculated using this equation:

$$\text{efficiency} = \frac{\text{(useful energy transferred by the device)}}{\text{(total energy supplied to the device)}}$$

Worked example

Calculate the efficiency of the old-style bulb shown in diagram D.

$$\text{efficiency} = \frac{\text{(useful energy transferred by the device)}}{\text{(total energy supplied to the device)}}$$

$$= \frac{9\text{ J}}{100\text{ J}}$$

$$= 0.09$$

The efficiency is a ratio so there are no units.

3 Calculate the efficiency of the low-energy light bulb shown in diagram D.

4 Look at diagram D in CP3a. Calculate the efficiency of the light bulb.

H

Reducing the amount of wasted energy can increase the efficiency of a device or a process. For mechanical processes, such as engines, this can mean reducing friction. It can also mean finding ways to make sure all the fuel going into an engine is burned, or finding a way of using the energy transferred by heating that would otherwise be wasted.

5 Explain how the efficiency of a bicycle can be increased.

Exam-style question

Kettle A transfers 200 J of energy to boil some water. Kettle B transfers 250 J to boil the same volume of water. Explain which kettle is more efficient. *(3 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Explain why adding oil to door hinges makes the door easier and quieter to open.

S2 A radio is supplied with 50 J of energy and transfers 5 J of this by sound. Explain what happens to the rest of the energy and calculate the efficiency of the radio.

Extend

E1 A coal-fired power station has an efficiency of 0.4. Some of the energy wasted is stored in hot water that needs to be cooled down. The efficiency can be doubled if this hot water is used to heat nearby buildings. Explain how much useful energy is now transferred by electricity and how much is transferred by heating for each 1000 J of energy stored in the coal. Suggest what causes the remaining wasted energy and what happens to it.

CP3c Keeping warm

Specification reference: P3.9; P3.10

Progression questions

- What does thermal conductivity mean?
- What affects the rate at which buildings cool?
- How can insulation reduce unwanted energy transfers?

Did you know?

The best insulator is aerogel. This is a solid made from a silica or carbon framework with air trapped inside it. Aerogel is 99.8% air, and so it has an extremely low density. It has many uses, including insulation for space suits.

B The aerogel is protecting the hand from the heat of the flame.

1 A pan of water is heated on a cooker. Describe how:

5th **a** energy is transferred from the cooker to the water

5th **b** the energy spreads out through the water.

6th **2** Explain why bubble wrapping is a good insulating material.

It costs money to keep our houses warm. **Insulation** slows down the rate at which energy is transferred out of a house by heating.

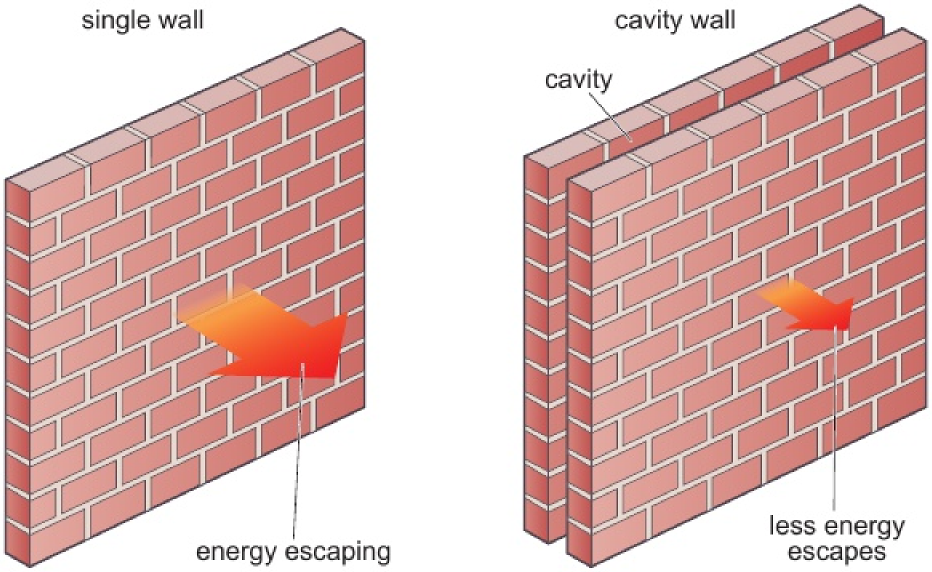
A This house is being built from straw bales. Straw is around 10 times better as an insulator than bricks.

Energy can be transferred by heating in different ways.

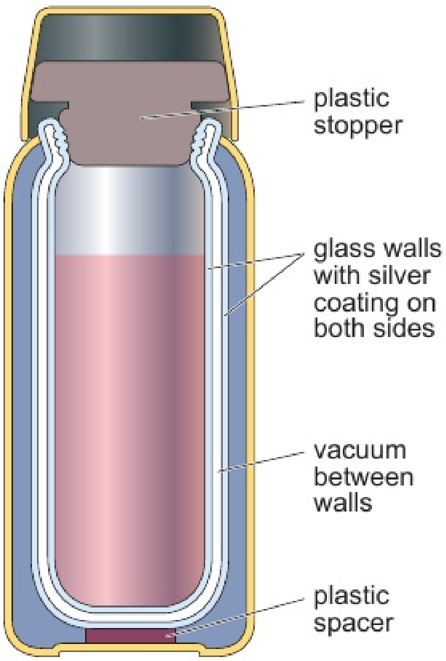
- In **conduction** vibrations are passed on between particles in a solid. Metals are good **thermal conductors** and materials such as wood are poor thermal conductors (good **thermal insulators**).
- In **convection** part of a **fluid** that is warmer than the rest rises and sets up a convection current.
- **Radiation** is the only way in which energy can be transferred through a vacuum. **Infrared radiation** can also pass through gases and some solid materials. Infrared radiation is **absorbed** and **emitted** easily by dull, dark surfaces, and is absorbed and emitted poorly by light, shiny surfaces.

The straw bales in photo A have a low **thermal conductivity**. This means that energy is not transferred through them very easily by heating. Materials that contain air are good insulators because air has a very low thermal conductivity. When air is trapped it cannot form convection currents and so does not transfer much energy.

The rate at which energy is transferred through a material by heating depends on its thickness, on its thermal conductivity and also on the temperature difference across it. The rate of energy transfer is reduced by increasing thickness, decreasing thermal conductivity and decreasing temperature difference.



C Modern brick walls are built from two layers with a cavity (air gap) between them, which helps to insulate a house.



D A 'vacuum flask' is often used to store hot or cold liquids and uses a combination of different materials to reduce energy transfer by heating.

6 The container in diagram D keeps hot drinks hot but also keeps cold drinks cold. Explain how it can do this.

Exam-style question

Energy is needed to keep homes warm in the winter. Explain how the thermal conductivity of the walls in a house affects the energy needed to keep a house warm. *(2 marks)*

3 **a** Look at photo B. Do you think the aerogel has a higher or lower thermal conductivity than straw bales?

b Explain how you worked out your answer to part a.

4 Straw bale houses have very thick walls. Give two reasons why the walls in the house in photo A are better insulators than normal brick walls.

5 Look at diagram C.

a Give two reasons why the cavity wall keeps a house warmer than a single wall.

b Suggest why modern buildings have the cavity filled with foam or a similar material.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Explain two ways in which walls can be built to keep a house warmer.

S2 Explain two ways in which insulation is used at home to reduce energy transfers.

Extend

E1 Look at diagram D. Explain which features of the flask reduce energy transfer by radiation, by conduction and by convection.

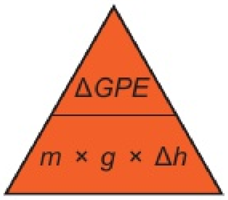
CP3d Stored energies

Specification reference: P3.1; P3.2

Progression questions

- What factors affect the gravitational potential energy stored in an object?
- How do you calculate gravitational potential energy?
- How do you calculate the amount of kinetic energy stored in a moving object?

A There are three heavy 'weights' on steel cables inside the Big Ben clock tower. They are lifted up three times a week to store the energy needed to drive the clock and the bells.



B This equation triangle can help you to change the subject of the equation. Δ is the Greek letter delta and stands for 'change in'.

Gravitational potential energy (GPE) is energy that is stored because of an object's position in a gravitational field. Any object that is above the surface of the Earth contains a store of gravitational potential energy. Every time something is moved upwards, it stores more gravitational potential energy.

The amount of GPE stored depends on the mass of the object, the strength of gravity and how far the object is moved upwards. It can be calculated using this equation:

$$\begin{matrix}\text{change in gravitational}\\\text{potential energy}\\\text{(J)}\end{matrix} = \begin{matrix}\text{mass}\\\text{(kg)}\end{matrix} \times \begin{matrix}\text{gravitational}\\\text{field strength}\\\text{(N/kg)}\end{matrix} \times \begin{matrix}\text{change in}\\\text{vertical height}\\\text{(m)}\end{matrix}$$

This can be written as: $\Delta GPE = m \times g \times \Delta h$

where ΔGPE represents the change in gravitational potential energy
m represents mass
g represents gravitational field strength
Δh represents change in vertical height.

The value for gravitational field strength on Earth is approximately 10 N/kg.

Worked example W1

A 5 kg box stores an extra 25 J of GPE when it is lifted onto a shelf. Calculate the distance it was lifted.

$$\Delta h = \frac{\Delta GPE}{m \times g}$$

$$= \frac{25\,\text{J}}{5\,\text{kg} \times 10\,\text{N/kg}}$$

$$= 0.5\,\text{m}$$

1 The gravitational field strength on the Moon is about 1.6 N/kg. Explain why the GPE stored by an object lifted 1 metre above the Moon's surface is less than when it is lifted by 1 m on the Earth.

2 One 'weight' in the Big Ben clock tower has a mass of 100 kg.

a Calculate the change in the GPE when it is raised by 5 metres.

b How far does this 'weight' have to be lifted to store 3000 J of energy?

Did you know?

Some birds crack open the shells of nuts or animals they are going to eat by dropping them onto stones. The birds store gravitational potential energy in the shells by lifting them into the air.

Kinetic energy

Energy is stored in moving objects. We call this kinetic energy. The amount of kinetic energy stored in a moving object depends on its mass and its speed.

Kinetic energy can be calculated using this equation:

$$\underset{\text{(J)}}{\text{kinetic energy}} = \frac{1}{2} \times \underset{\text{(kg)}}{\text{mass}} \times \underset{\text{(m/s)}^2}{\text{(speed)}^2}$$

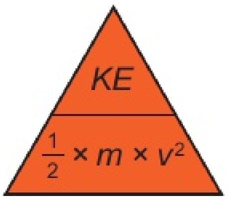
This can be written as:

$$KE = \frac{1}{2} \times m \times v^2$$

where KE represents kinetic energy

m represents mass.

v represents speed.



D

Worked example W2

A cricket ball with a mass of 160 g is bowled at a speed of 30 m/s. How much kinetic energy is stored in the moving ball?

160 g = 0.16 kg

$$KE = \frac{1}{2} \times m \times v^2$$

$$= \frac{1}{2} \times 0.16\text{ kg} \times (30\text{ m/s})^2$$

$$= 72\text{ J}$$

3 Calculate the kinetic energy stored in the following.

7th **a** A 2 kg toy robot dog walking at 2 m/s.

7th **b** A boy on a bike riding at 8 m/s. The mass of the boy and his bike is 70 kg.

8th **4** A whale swimming at 7 m/s stores 98 000 J of kinetic energy. Calculate the mass of the whale.

Exam-style question

Explain why a car moving at 20 m/s is storing more kinetic energy than a cyclist moving at 2 m/s. *(2 marks)*

C The heavy disc at the bottom of this potter's wheel stores energy while it is spinning.

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 A missile is flying at 220 m/s at 100 m above the sea. Its mass is 1000 kg. Calculate its:

- **a** gravitational potential energy
- **b** kinetic energy.

Extend

E1 A crow drops a 15 g walnut from 5 m above the ground. Calculate the amount of GPE stored in the nut just before it fell.

E2 Assume all the GPE stored in the walnut was transferred to kinetic energy just before it reached the ground. How fast was it moving when it hit the ground?

CP3e Non-renewable resources

Specification reference: P3.13; P3.14

Progression questions

- What non-renewable energy resources can we use?
- How are the different non-renewable resources used?
- How is the use of non-renewable energy resources changing?

A The New Horizons space probe was launched in 2006 and flew past Pluto in 2015. Power for the spacecraft is provided by energy stored in a radioactive nuclear fuel.

Nuclear fuels such as **uranium** store a lot of energy in a small piece of material. This makes nuclear fuels very useful for spacecraft, where the mass of the fuel is important.

Most of the electricity used in the UK is generated using nuclear fuels or **fossil fuels** such as coal, oil and natural gas. These are all **non-renewable** energy resources, which means they will run out one day.

Petrol and diesel are fossil fuels made from oil. They are used in most vehicles, aeroplanes and ships because they store a lot of energy and they are easy to store and to use in engines. Another fossil fuel, natural gas, is burnt to heat homes or for cooking.

5th **1** Describe two reasons why fuels made from oil are used in vehicles.

Burning fossil fuels release carbon dioxide and other gases. Carbon dioxide emissions contribute to **climate change**. Other emissions from power stations and vehicles cause further pollution problems. There are various ways of reducing this pollution, but these cost money.

Burning natural gas causes less pollution than burning coal. Natural gas power stations also emit less carbon dioxide than other fossil-fuelled power stations producing the same amount of electricity.

B Accidents with oil rigs or oil tankers can pollute large areas, harming wildlife.

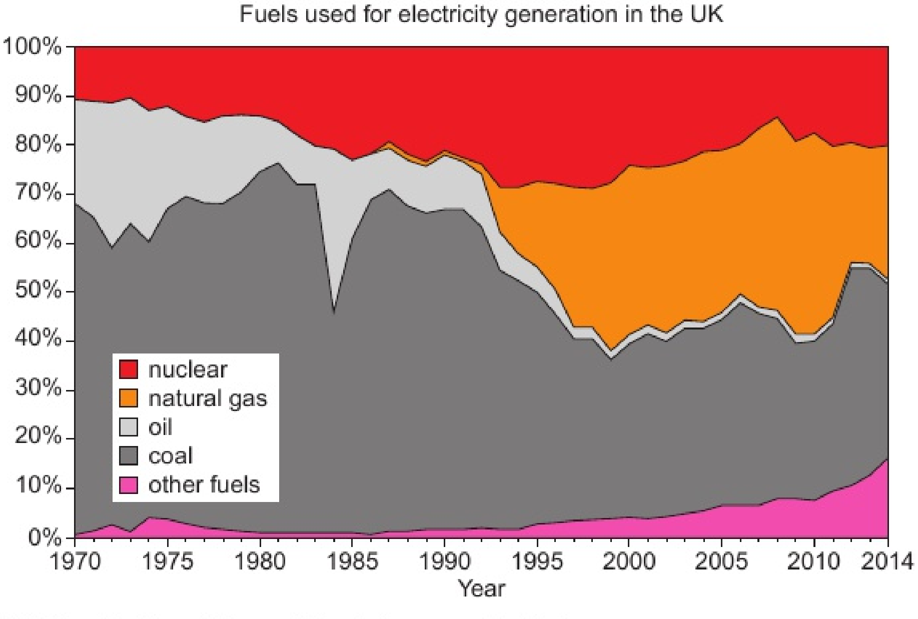
5th **2** Describe two advantages of using natural gas instead of coal to generate electricity.

Nuclear power stations do not emit any carbon dioxide or other gases. However, the waste they produce is radioactive and some of it will stay radioactive for millions of years. This is expensive to dispose of safely. It is also very expensive to decommission (dismantle safely) a nuclear power station at the end of its life. It costs a lot more to build and to decommission a nuclear power station than a fossil-fuelled one.

There are not many accidents in nuclear power stations and the stations are designed to contain any radioactive leaks. However, if a major accident occurs it can have very serious consequences.

C In 2011 a tsunami swept over a nuclear power station in Japan and damaged it. Radioactive materials were released into the atmosphere. Some of this polluted the sea nearby and then spread across the Pacific Ocean.

Most countries in the world are trying to cut down the use of fossil fuels. This will reduce pollution and also help to make supplies of the fuels last longer. **Renewable** resources are energy resources such as solar or wind energy that will not run out. Most renewable resources do not emit polluting gases.



D 'Other fuels' on this graph include renewable fuels.

6 Look at graph D. Describe how the energy resources the UK uses for generating electricity have changed since 1970.

Exam-style question

State two reasons why many countries are trying to reduce the amount of non-renewable fuel they use. *(2 marks)*

3 **a** Write down one advantage of nuclear power over fossil-fuelled power stations.

b Write down two disadvantages.

4 **a** Why do you think a nuclear power station costs more to build?

b Why is decommissioning it properly very important?

5 How can a nuclear accident affect people in many different parts of the world?

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Name four different non-renewable fuels and describe how they are used.

S2 Suggest why the use of renewable energy resources has been increasing in the UK in recent years.

Extend

E1 List three different ways in which non-renewable fuels are used. Describe the advantages and disadvantages of each fuel for each use.

CP3f Renewable resources

Specification reference: P3.13; P3.14

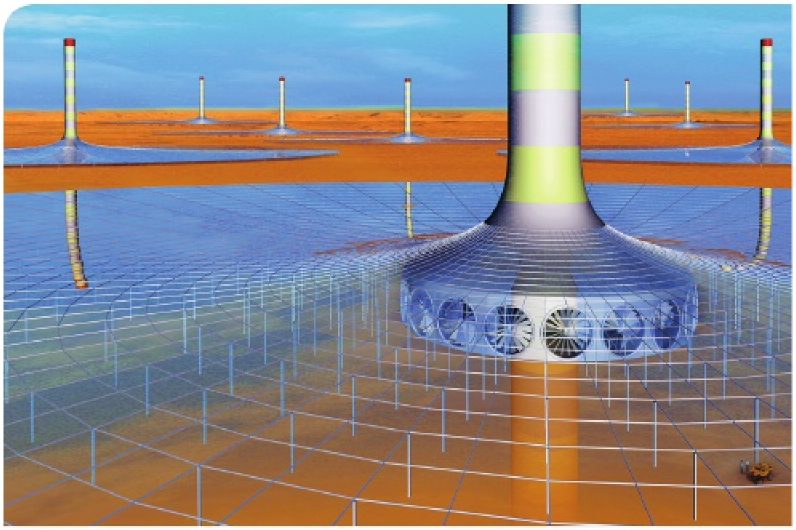
Progression questions

- What renewable energy resources can we use?
- How are the different renewable resources used?
- How is the use of renewable energy resources changing?

Renewable energy resources are resources that will not run out. Most renewable energy resources do not cause pollution or emit carbon dioxide when used to generate electricity because no fuel is burned.

1 What advantage do almost all renewable energy resources have over fossil fuels for generating electricity?

Solar cells convert **solar energy** directly into electrical energy, in 'solar farms' or on house roof-tops. Solar energy can also be used in power stations such as the one in diagram A or the one on the opening page of this unit. Solar energy can also be used to heat water for use in homes. Solar energy is not available all the time.



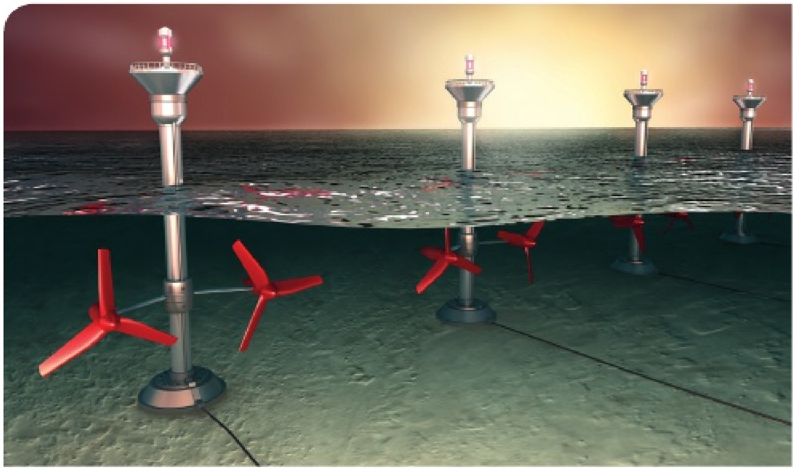
A In a solar chimney power station, solar energy heats the air under the glass. The hot air rises up the tower, turning turbines as it moves.

2 Describe two ways in which electricity can be produced using energy from the Sun.

Hydroelectricity is generated by falling water in places where water can be trapped in high reservoirs. It is available at any time (as long as the reservoir does not dry up). A hydroelectric power station can be started and stopped very quickly unlike fossil fuel power stations.

Wind turbines can be used to generate electricity as long as the wind speed is not too slow or too fast. A lot of wind turbines are needed to produce the same amount of energy as a fossil-fuelled power station and some people think they spoil the landscape.

Tidal power can generate electricity when turbines in a huge barrage (dam) across a river estuary turn as the tides flow in and out. Tidal power is not available all the time but is available at predictable times. There are not many places in the UK that are suitable for barrages and they may affect birds and other wildlife that live or feed on tidal mudflats. Underwater turbines can be placed in water currents in the sea to generate electricity, as seen in Figure B.



B artist's impression of tidal stream turbines

3 Describe two ways in which electricity can be produced using tides.

Bio-fuels can be used in the same ways as fossil fuels. They are made from animal wastes or from plants. Bio-fuels can be made from waste wood or the parts of plants that are not used for food, but some crops are grown specifically to be made into bio-fuels. Bio-fuels are called **carbon neutral** because when they burn, they release the same amount of carbon dioxide that they took from the atmosphere when the plants grew. However, energy is also needed to grow and harvest the crops and to turn them into fuel, so most bio-fuels are not really carbon-neutral.

Electricity can also be generated from waves or from hot rocks underground.

NO FOOD FUEL
STOP
FOOD NOT FUEL
Food should feed people not fill cars

C Some people object to growing crops for fuel because this reduces the land available for farming food and can increase food prices.

We cannot only use renewable resources to generate electricity because most are not available all the time. It also takes a lot of land to obtain energy from bio-fuels or other renewable resources such as solar farms.

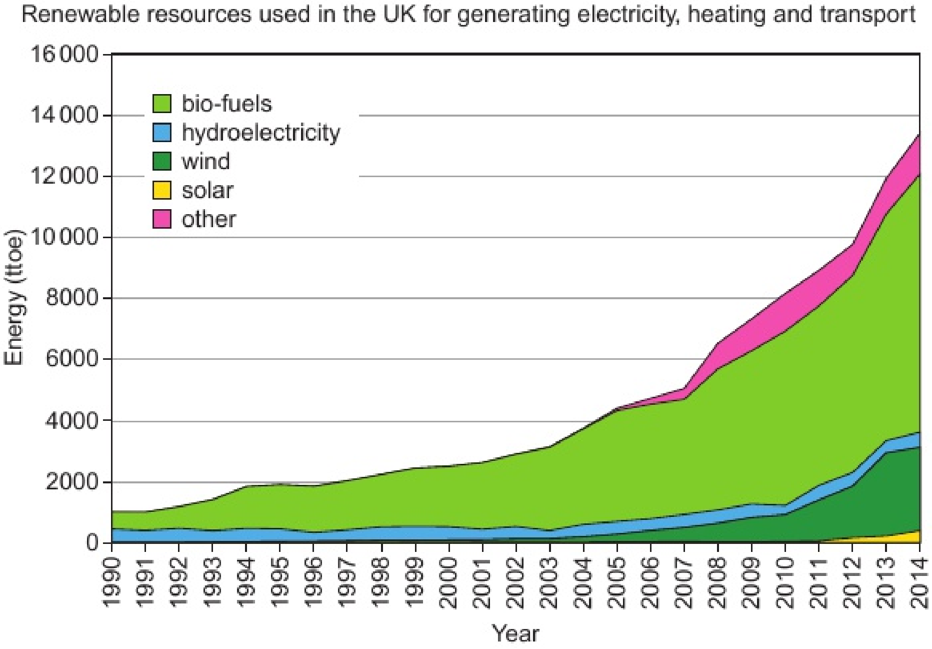
4 State which renewable resources:

a are available all the time

b are available at predictable times

c can only be used in certain places

d depend on the weather.



D On the graph, 'other' includes wave, tidal, geothermal and biofuel resources. The unit 'ttoe' (thousand tonnes of oil equivalent) is used to make fair comparisons between energy resources.

5 Look at graph D.

a Describe how the use of renewable energy has changed since 1990.

b Suggest two reasons for the changes you have described.

Exam-style question

State one advantage and one disadvantage of using renewable resources for generating electricity. *(2 marks)*

Checkpoint

How confidently can you answer the Progression questions?

Strengthen

S1 Describe five renewable energy resources and how they are used.

S2 State two advantages of a hydroelectric power station compared with a natural gas power station.

Extend

E1 Explain why we would need an efficient way of storing electricity before we could generate all our electricity from renewable resources. Give examples to support your answer.

Generating electricity

Hydroelectric power and solar power can be used as alternatives to fossil fuels.

Assess hydroelectric power and solar power as energy resources for the large-scale generation of electricity in the UK. (6 marks)

Student answer

Both these resources are renewable, and they do not produce gases that harm the environment. Using these resources would help to reduce the gases put into the air by burning fossil fuels [1]. *Hydroelectricity is available at any time, but solar energy is only available during the day and if the clouds are not too thick* [2]. *Not many places in the UK are suitable for building the reservoirs for hydroelectricity, and they can affect wildlife and habitats. Solar panels need to cover large areas of land to produce the same amount of electricity as a fossil-fuelled power station, and there is not enough sunshine in the UK to produce a lot of electricity* [3]. *So neither resource is really good enough to produce enough electricity to replace fossil fuels for generating electricity* [4].

[1] The student has given some advantages that apply to both resources compared to using fossil fuels.

[2] This sentence considers the availability of hydroelectricity and solar power.

[3] This section explains the limitations of using hydroelectricity and solar power in the UK.

[4] The last sentence provides a final conclusion, and links this to the use of fossil fuels as mentioned in the question.

Verdict

This is a strong answer. It clearly lists the factors that affect the use of the two renewable resources and provides a conclusion. The ideas are presented clearly and in a logical order. The answer links scientific ideas together, for example, that burning fossil fuels produces gases and that these gases can harm the environment. The use of scientific language is good.

Exam tip

If a question asks you to 'assess' something, you need to consider all the factors that apply, and consider which are the most important. Most 'assess' questions require you to draw a conclusion.

Published by Pearson Education Limited, 80 Strand, London, WC2R 0RL.

Copies of official specifications for all Edexcel qualifications may be found on the website:
www.edexcel.com

Text © Mark Levesley, Penny Johnson, Sue Kearsey, Iain Brand, Nigel Saunders, John Ling, Sue Robilliard

Series editor: Mark Levesley
Designed by Poppy Marks, Pearson Education Limited
Typeset by Phoenix Photosetting, Chatham, Kent
Illustrated by KJA Artists Illustration Agency and Phoenix Photosetting, Chatham, Kent.
Original illustrations © Pearson Education Limited
Cover design by Poppy Marks and Colin Tilley Loughrey
Picture research by Ruth Smith
Cover photo © Science Photo Library Ltd: NASA

The rights of Mark Levesley, Penny Johnson, Sue Kearsey, Iain Brand, Nigel Saunders, John Ling and Sue Robilliard to be identified as authors of this work have been asserted by them in accordance with the Copyright, Designs and Patents Act 1988.

First published 2015

ISBN 9780997865578

Copyright notice

All rights reserved. No part of this publication may be reproduced in any form or by any means (including photocopying or storing it in any medium by electronic means and whether or not transiently or incidentally to some other use of this publication) without the written permission of the copyright owner, except in accordance with the provisions of the Copyright, Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency, Saffron House, 6–10 Kirby Street, London EC1N 8TS (www.cla.co.uk). Applications for the copyright owner's written permission should be addressed to the publisher.

Printed in the UK by Belmont Press Ltd.

Acknowledgements

The following authors contributed text to previous Pearson publications and the publishers are grateful for their permission to include elements of their work: Ann Fullick, James de Winter, Miles Hudson. The publishers would like to thank Jennifer Stafford-Brown for her contribution to CB2a Mitosis.

A note from the publisher, Pearson Education Limited

This free support resource is based on the July 2015 Draft 1.0 of the specification and at the time of publication was awaiting accreditation. The specification is therefore subject to change.

This free support resource has not been reviewed or endorsed by Edexcel and should not be considered an official Edexcel publication.

While the publishers have made every attempt to ensure that advice on the qualification and its assessment is accurate, the official specification and associated assessment guidance materials are the only authoritative source of information and should always be referred to for definitive guidance.

Pearson examiners have not contributed to any sections in this resource relevant to examination papers for which they have responsibility.

Examiners will not use this free support resource as a source of material for any assessment set by Pearson.

This free support resource is not required to achieve this Pearson qualification or to begin teaching the qualification in Year 9. It is not necessarily the only suitable material available to support the qualification, and any resource lists produced by the awarding body shall include this and other appropriate resources.

The authors and publisher would like to thank the following individuals and organisations for permission to reproduce photographs and text.

Photographs

123RF.com: CP3F(B), Aleksandar Mijatovic CP2E (A), Michael Lane CB2A (C), quintanilla CP3, Sebastian Kaulitzki CB2B (Ca), Wichit Sawatdee CB3F (B); **Alamy Images:** Andrey Nekrasov CP2A (D), Arctic Images CC1A (A), Bax Walker CP3C (C), Cliff Hide News CP2H (A), Craig Ruttle CP3E (B), David Gee CB1E (B), David Wall CP2D (D), incamerastock CP2G (D), INTERFOTO CB1A (C), Jim West CP1A (D), Jon Bower UK CC4B (A), Julie Edwards CP2A (A), RosalreneBetancourt 4 CP2F (A), sciencephotos CP3B (A), Stocktrek Images, Inc. CP1C (A), sutdiomode CC1B (C), The Natural History Museum CB1, Vicky Beaver CC2B (A); Barcroft Media: Amos Nachoum CB2; **Brian J Ford, Cambridge:** CB1B (A); **Corbis:** Amanda Brown/Star Ledger CP2G (B), Anthony Rakusen/Cultura CC2C (B), Facundo Arrizabalaga/epa CP2G (A), Henrik Trygg CP2B (B), Louie Psihoyos CB1H (A), Michael Wheatley, All Canada Photos CP1A (A), Nagasaki Atomic Bomb Museum/epa CC3C (B), Olivier Hoslet/epa CP3F (C), STR/epa CP3E-C, Transtock CP3A (B); **Courtesy of The OceanCleanup www.theoceancleanup.com:** CC1/CC2; **Developed in the laboratory of Associate Professor Joan Heath in the Development and Cancer Division at the Walter and Eliza Hall Institute of Medical Research in Melbourne, Australia:** CB2D (B & D); **Fotolia.com:** nikkytok CC2D (A); **Garden World Images:** CB3F (A); **Genetic portrait by Ulric Collette:** CB3; **Geoffrey Whiteway:** CB1D (A); **Getty Images:** AFP/Francois Guillot CC2C (A), AFP/Justin Tallis CB3B (D), AFP/MOHD EASFAN CP2D (A), Bryn Lennon CP1A (B), Ed Reschke CB1B (B), John Chapple CP1B (A), PBNJ Productions CB2B (A), Photolibrary/R. Andrew Odum CB2D (A), Roger Jackman, Oxford Scientific CB1E (A), Rusty Jarrett CP1D (A), Taxi CP2H (B), Tom Shaw CC3A (D); **GNU Free Documentation License: Wikipedia:** NikNaks (own work) CC4A (B); **Dr. Gunther von Hagens, BODY WORLDS, Institute for Plastination, Heidelberg, Germany, www.bodyworlds.com:** CB2E (B); **NASA:** CP3E (A); **Nature Picture Library:** Fred Olivier CP1, Nature Production CB1F (A); **Pasca lab, Stanford University:** CB2E (A); **Pearson Education Ltd:** CC1B (B), CC2E (B), Jon Barlow CB3A (C), Tsz-shan Kwok CC3A (A); **Reproduced with permission of D. Pearmain, S. J. Park, Z. W. Wang, A. Abdela, R. E. Palmer and Z. Y. Li; University of Birmingham:** CC3; **Reuters:** Antonio Bronic CP2E (D), Daniel Munoz CP2D (B); **Rex Features:** Eddie Boldizsar CP2B (A), Imaginechina CP2A (B), Rex Shutterstock CB2F (A); **Robert Harding World Imagery:** Ashley Cooper CP3B (B); **Science & Society Picture Library:** Science Museum CB1A (A); **Science Photo Library Ltd:** CC4, CP2C (A), Alan Sirulnikoff CP3D (A), Andrew Lambert Photography CC5A (A), Biophoto Associates CB1A (B), CNRI CB1D (B), Collection CNRI/Overseas CB2B (Cc), Dirk Wiersma CC5B (B), Dr Gopal Murti CB1B (C), CB1D (C), Dr P. Marazzi CB3E (B), Dr. John Brackenbury CP3C (B), Edward Kinsman CP3A (A), Gary Hincks CC5B (C), Hans-Ulrich Osterwalder CP3F (A), Javier Trueba CC2B (B), Kenneth Eward/Biografx CB1F (B), Mark de Freye CC2B (C), NASA CP2H (D), NREL/US Department of Energy CP3D (B), Pascal Goetgheluck CB3A (B), Patrick Landmann CB3E (C), Power and Syred CB2C (C), Steve Gschmeissner CB2B (Cb), Tony Camacho CC5C (B), TRL LTD CP2H (C); **Shutterstock.com:** Baloncici CC4A (A), biletskiy CP3C (A), cleanfotos CP2B (C), Domenic Gareri CC4C (A), Galyna Andrushko CB1G (A), Harper 3D CB1A (D), Ivan Garcia CP2B (D), Jose Luis Calvo CB2B (Cd), Keith Publicover CP2E (B), Martijn Smeets CP2A (C), Paul Fleet CC3B (B), Sakaowrat CB2A (D), sunny337 CC1B (A), Taiga CB3E (A), Tatiana Belova CP2, Timothy Epp CC2E (A), Vadim Petrakov CB2C (A); **The Defence Picture Library:** CP1C (C); **University of California, Berkeley:** Felix R. Fischer Ph.D, Department of Chemistry CC5/CC6/CC7; **University of Leicester:** CB3B (C); **Wellcome Library, London:** Yorgas Nikas CB1C (B)

All other images © Pearson Education

Text

CC3 Atomic Structure opener paragraph on page 33 adapted from Professor Richard Palmer, The Nanoscale Physics Research Laboratory, University of Birmingham. Reproduced with the permission of Professor Richard Palmer.

Figures

CB2b graph B from **Department of Health 2009 www.rcpch.ac.uk/system/files/protected/page/A4%20Boys%200-4YRS%20%284th%20Jan%202013%29.pdf**, contains public sector information licensed under the Open Government Licence v3.0; CP3e graph D from **https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/454484/DUKES_2015_Long_Term_Trends.pdf**, DECC Contains public sector information licensed under the Open Government Licence v3.0

Every effort has been made to contact copyright holders of material reproduced in this book. Any omissions will be rectified in subsequent printings if notice is given to the publishers.

Websites

Pearson Education Limited is not responsible for the content of any external internet sites. It is essential for tutors to preview each website before using it in class so as to ensure that the URL is still accurate, relevant and appropriate. We suggest that tutors bookmark useful websites and consider enabling students to access them through the school/college intranet.

The Periodic Table of the Elements

1	2											3	4	5	6	7	0
							1 **H** hydrogen 1										4 **He** helium 2
7 **Li** lithium 3	9 **Be** beryllium 4		**Key** relative atomic mass **atomic symbol** name atomic (proton) number									11 **B** boron 5	12 **C** carbon 6	14 **N** nitrogen 7	16 **O** oxygen 8	19 **F** fluorine 9	20 **Ne** neon 10
23 **Na** sodium 11	24 **Mg** magnesium 12											27 **Al** aluminium 13	28 **Si** silicon 14	31 **P** phosphorus 15	32 **S** sulfur 16	35.5 **Cl** chlorine 17	40 **Ar** argon 18
39 **K** potassium 19	40 **Ca** calcium 20	45 **Sc** scandium 21	48 **Ti** titanium 22	51 **V** vanadium 23	52 **Cr** chromium 24	55 **Mn** manganese 25	56 **Fe** iron 26	59 **Co** cobalt 27	59 **Ni** nickel 28	63.5 **Cu** copper 29	65 **Zn** zinc 30	70 **Ga** gallium 31	73 **Ge** germanium 32	75 **As** arsenic 33	79 **Se** selenium 34	80 **Br** bromine 35	84 **Kr** krypton 36
85 **Rb** rubidium 37	88 **Sr** strontium 38	89 **Y** yttrium 39	91 **Zr** zirconium 40	93 **Nb** niobium 41	96 **Mo** molybdenum 42	[98] **TC** technetium 43	101 **Ru** ruthenium 44	103 **Rh** rhodium 45	106 **Pd** palladium 46	108 **Ag** silver 47	112 **Cd** cadmium 48	115 **In** indium 49	119 **Sn** tin 50	122 **Sb** antimony 51	128 **Te** tellurium 52	127 **I** iodine 53	131 **Xe** xenon 54
133 **Cs** caesium 55	137 **Ba** barium 56	139 **La*** lanthanum 57	178 **Hf** hafnium 72	181 **Ta** tantalum 73	184 **W** tungsten 74	186 **Re** rhenium 75	190 **Os** osmium 76	192 **Ir** iridium 77	195 **Pt** platinum 78	197 **Au** gold 79	201 **Hg** mercury 80	204 **Tl** thallium 81	207 **Pb** lead 82	209 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111	Elements with atomic numbers 112-116 have been reported but not fully authenticated						

***The lanthanoids (atomic numbers 58-71) and the actinoids (atomic numbers 90-103) have been omitted.**

The relative atomic masses of copper and chlorine have not been rounded to the nearest whole number.